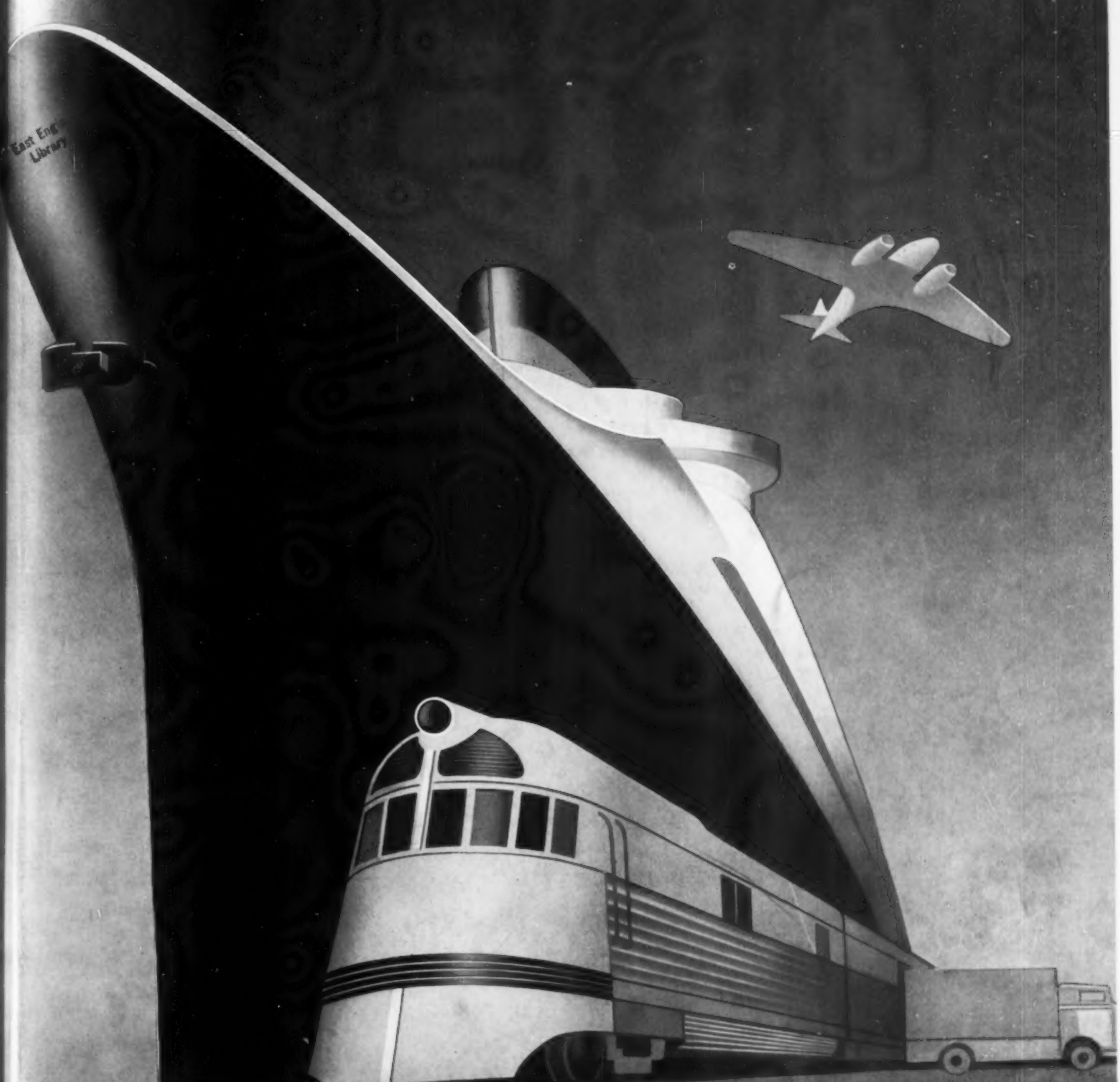
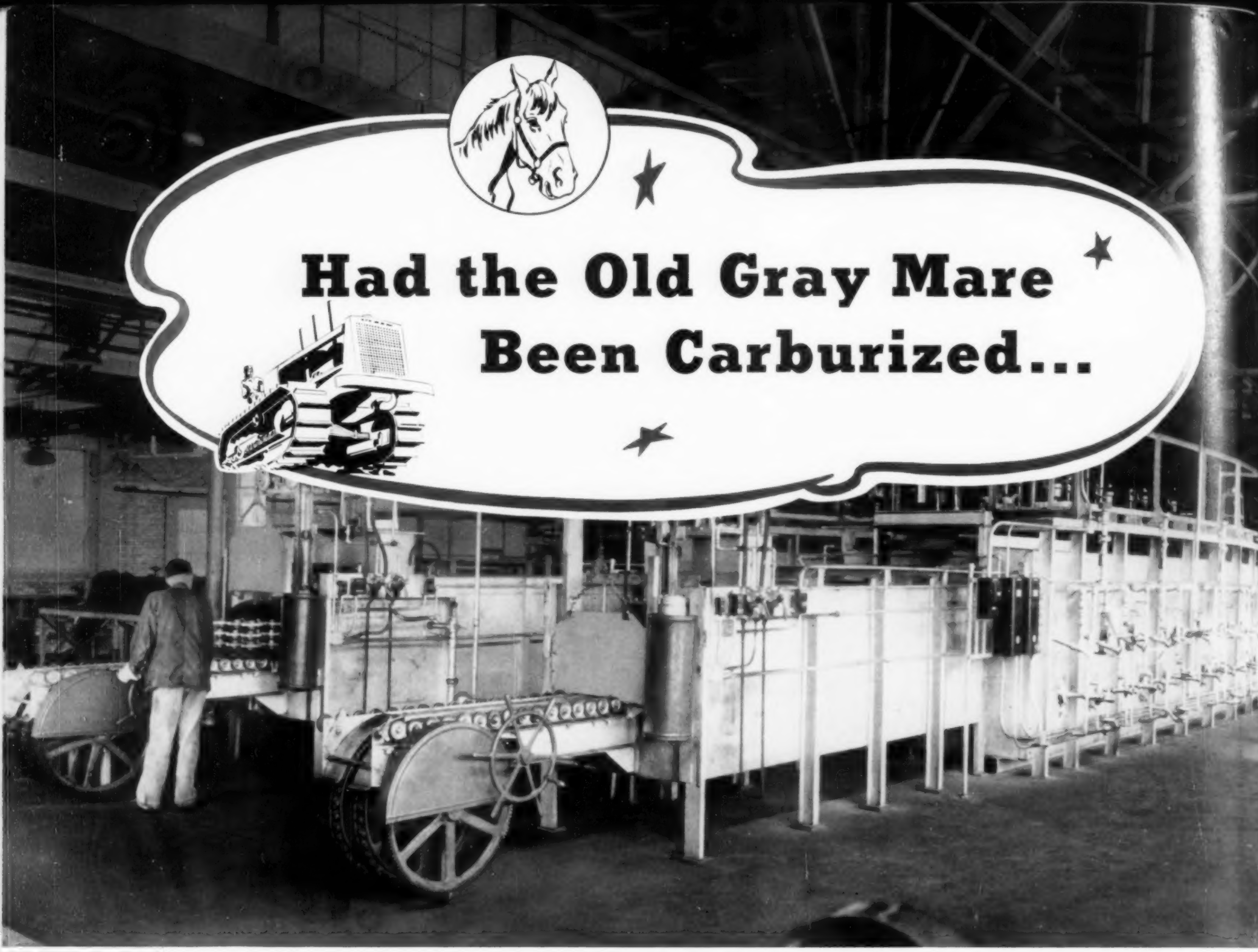
METAL PROGRESS

JUNE ~ 1940





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June, 1940
Volume 37, No. 6

Metal Progress

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By Clarence L. Altenburger
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Improving Drawability of Steel by Controlling Nitrogen

CHANGES in the physical condition of soft steel sheet occurring in the time between final rolling in the steel mill and fabrication in the customer's plant have caused much trouble to both producer and consumer. Perhaps nowhere has this generally undesirable characteristic been felt more keenly than in the production and use of deep drawing steels, chiefly because of the astonishing rapidity with which production schedules in the consumer's plant are upset to the consequent ensuing grief of the steel producer when such steels are not fabricated within a short time after temper rolling. The trouble has become acute in recent times because of the steadily increasing depth and complexity of draw and the much higher standards of surface finish that are insisted upon.

Another serious consideration has received less public discussion, and that is the embrittling changes in such steels *after* they have been successfully fabricated and are in service. A gradual, but swift, increase in the use of flat stock in fabricating structures of various types by bending, forming, coining and other cold working processes, has often supplanted established methods of hot working or of casting steel into required shapes. As a consequence a vast number of structures, especially in mobile equipment, are in some condition of cold work wherein strain aging can take place to the impairment of the ductility and notched bar resistance of the steel comprising the structure. The complex stresses existing or likely to exist at times in mobile equipment may lead to early, brittle failure in normal service.

Both these dangers — troubles in deep drawing, and embrittlement in service — are but two aspects of one phenomenon frequently called "strain aging". Students of this problem are agreed that a clear correlation exists between strain aging and "blue brittleness" and an extensive literature has already grown up around this subject. Blue brittleness, in turn, is easy to measure experimentally, by the gain in tensile strength in the neighborhood of 450° F. over that at room temperature and the corresponding decrease in ductility (elongation at fracture). While it is easy to show the presence or the absence of blue brittleness (strain aging) in a heat of steel, it is not so easy to say what chemical constituent in the steel or what detail of furnace or fabrication practice is responsible for it.

It is the purpose of this article to enumerate certain experiments which have shed light on the causes of blue brittleness or strain aging in steel and to show how the tendency of steel to strain age can be placed at any desired level of "ageability". In some cases it has been desirable to run up the temperature of testing to 600° F. It is clear that by the blue brittleness test, steel can be treated by any desired procedure and the effect of such treatment on strain aging can be quickly and decisively determined.

Reliable and much-used texts either imply or specifically state that blue brittleness is a normal attribute of iron. For example, Jeffries and Archer say on page 182 of "The Science of

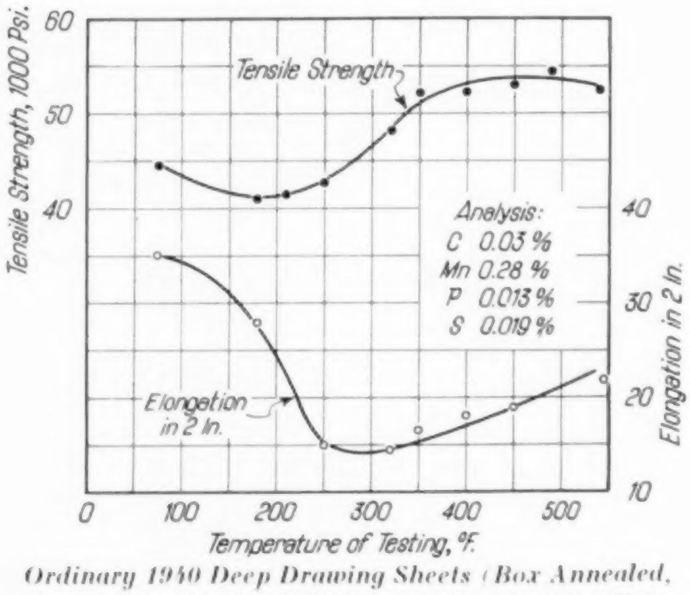
Metals": "Tensile tests at elevated temperatures show that iron actually has a higher tensile strength but lower elongation and reduction of area in the blue heat range than at room temperature." Our experiments lead us to doubt this. Insofar as we have been able to determine, a completely stable steel will have about 8000 psi. *less* tensile strength at approximately 450° F. than at room temperature, while the steels we have been able to produce most susceptible to strain aging have had about 28,000 psi. *greater* tensile strength at approximately 450° F. than at room temperature. We thus have a range of about 36,000 psi. — wide enough to make the test for blue brittleness, when properly conducted, very sensitive.

Effect of Gage and Heat Treatment

Gage and Kind of Steel	Temperature of Test	Tensile Strength as Dead Soft; Box Annealed	Annealed in Air *(a)*	Treated in Nitrogen *(b)*
20-g. rimmed steel	Room	47,215	44,885	43,155
	450° F.	59,880	66,890	61,780
	Diff.	*+12,665*	*+22,005*	*+18,625*
18-g. rimmed steel	Room	43,490	43,035	42,510
	450° F.	54,280	59,380	56,460
	Diff.	*+10,790*	*+16,345*	*+13,950*
18-g. stabilized steel	Room	41,675	42,966	44,255
	450° F.	40,050	45,980	44,175
	Diff.	*— 1,625*	*+ 3,014*	*—80*

(a) Annealed in air about 30 min. at 1660° F. (above critical).
(b) Heated 6 min. at 1700° F., slowly cooled, 6 hr. to room temperature, all in nitrogen.

Ordinarily, ingot irons and effervescing basic openhearth steel sheets processed by modern methods will show increases in the neighborhood of 11,000 psi. This figure varies somewhat in sheet produced by different steel



Ordinary 1940 Deep Drawing Sheets (Box Annealed, Openhearth Steel) Exhibit Considerable Blue Brittleness. Tensile strength at 450° F. (54,000 psi.) is 9500 psi. above strength at room temperature

producers. For instance, tests made on sheet from one source from time to time were fairly consistent at about 13,000 psi. increase, while steel from a second source had consistently about 9000. These are, however, minor variations and are, we believe, without practical significance. Upon rare occasion, sheet from any one mill will depart slightly from the value usual for that mill. The first set of curves shows typical values for box annealed, basic openhearth, deep drawing sheets. Tensile specimens on sheet stock are standard (in all cases) ½-in. wide by 2-in. gage length.

We found early that annealing in air increased the spread between the tensile strength at elevated temperatures and at room temperature. Data for various gages are in the table above for both rimmed steels and a stabilized killed steel whose ladle analyses were both 0.06 to 0.08% carbon, 0.35 to 0.45% manganese, 0.02% max. phosphorus, 0.03% max. sulphur. The effect of re-annealing on the various gages is quite marked.

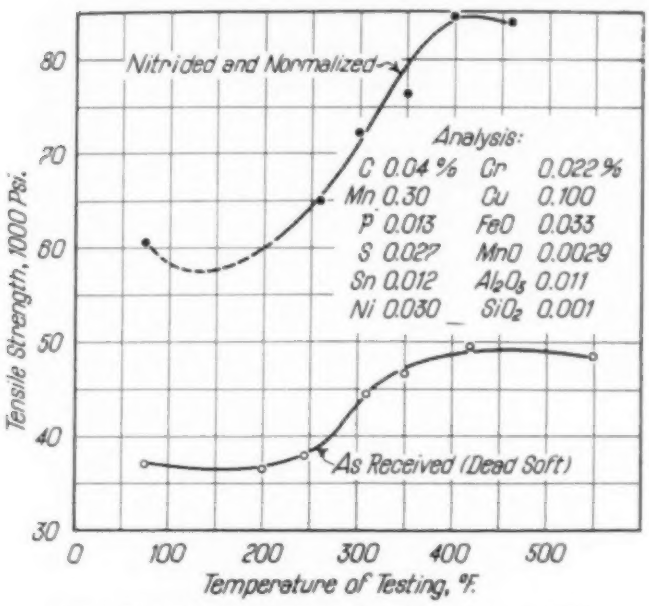
Heating in cylinder nitrogen for short times is also very influential. The "as-received" steels noted in the first table were heated in a tubular furnace, held above the upper critical temperature for about six minutes and then cooled to room temperature in a flow of nitrogen in about six hours. It is obvious that nitrogen cannot be used freely as a protective atmosphere as it is not inert. In an attempt to accentuate this nitrogen effect, some low car-

Effect of Nitriding Hand Rolled Sheet

Temp. of Test	Before Nitriding	After Nitriding *(a)*	Nitrided and Normalized *(b)*
Room	44,700	51,600	59,400
500° F.	55,080	72,500	87,250
Diff.	*+10,380*	*+20,900*	*+27,850*

(a) Nitrogen mostly in nitrided case.
(b) Normalized and slowly cooled from 1100° F.

bon sheet (hand rolled of 0.062% phosphorus steel, box annealed) was nitrided in dry ammonia gas for 60 min. at 950° F. Results are shown at the bottom of page 640. The normalizing treatment referred to in the table served to equalize the nitrogen content throughout the thickness of the sheet. Prior to normalizing, the vast majority of the nitrogen introduced by



Dead Soft Steel Is Greatly Strengthened by Increasing Its Nitrogen Content, but Its Blue Brittleness Is Also Greatly Increased

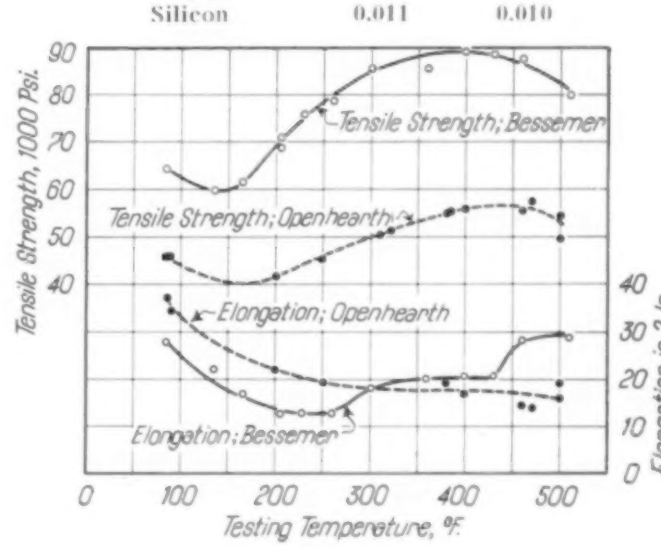
nitriding was present as a case. The curves above give further results with the use of dry ammonia gas on another heat of steel whose analysis is shown. Nitriding in ammonia for 60 min. at 950° F., followed by normalizing and slow cooling from 1100° F. to diffuse the nitrided case not only increased the strength at room temperature by 50% but also accentuated the blue brittleness (gain in strength at 450° F.).

The results recorded above have been found to be consistent with those obtained on a box annealed sheet made by the bessemer process. The tests are compared with basic openhearth steel in the curves at the right. The bessemer sheet was 0.070 in. thick while the basic openhearth sheet was 0.035 in. thick; in comparing elongations, therefore, the greater cross-sectional area of the bessemer sheet should be taken into consideration since it yields greater percentages of elongation. Both steels were of rimmed grade.

Thus far it can be seen that at temperatures slightly above room temperature the tensile strength is less. This minimum in basic openhearth sheet usually occurs in the range 175 to 210° F. Above this the tensile strength increases and is again equal to the room temperature tensile strength in the range between 250 and 275° F. Steels of higher nitrogen content, however, find their minimum tensile strengths at lower temperatures. Thus the bessemer steel of the third figure has its minimum strength at 135° F., and at approximately 180° F. the tensile strength has again become equal to that at room temperature. The maximum increase in tensile strength for the bessemer sheet is at 400° F. and is about 25,000 psi. higher than at room temperature and about 29,000 psi. higher than its minimum. In the basic openhearth sheet, however, the maximum comes at about 470° F. and is 12,000 psi. higher than the room temperature tensile strength and about 17,000 higher than its minimum. The mini-

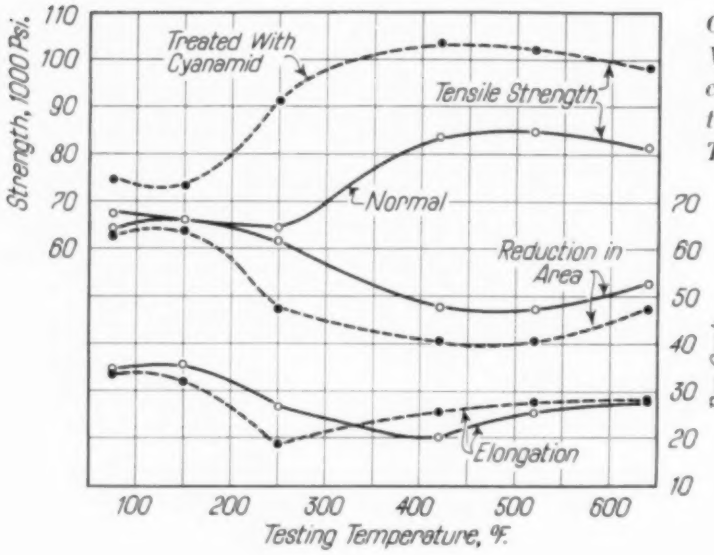
Box Annealed, Rimmed Bessemer Steel Sheet (0.070 In. Thick) Strain Ages Considerably More Than Rimmed Openhearth Steel (0.035-In. Sheet). Comparative analyses:

	Bessemer	Openhearth
Carbon	0.07%	0.03%
Manganese	0.44	0.27
Phosphorus	0.104	0.012
Sulphur	0.041	0.025
Silicon	0.011	0.010



mum elongations also come at lower temperatures for the higher nitrogen steels.

Similar results can be obtained by doctoring an ingot, during teeming, with a nitrogen-bearing compound such as calcium cyanamid. The results of such treatment are depicted on the next page for standard 0.505-in. specimens machined from a 0.888-in. hexagon of free-machining steel. In this case, also, the



One Ingot From a Heat of Free-Machining Steel Was Nitrided, While Teeming, by Adding Calcium Cyanamid, and the Steel Shows Characteristic Tensile Results When Tested Above Room Temperature (Standard 0.505-In. Specimens)

higher nitrogen steel has a lower minimum temperature since its tensile strength at 250° F. is already 16,500 psi. *greater* than at room temperature whereas companion specimens from an untreated ingot are about 3000 psi. *less* at 250° F. than at room temperature. Likewise, the peak strength temperature is lower and the gain in tensile strength at the peak is higher. The ductility decreases more rapidly with temperature in the higher nitrogen steel and the minimum elongation occurs at a lower temperature.

Early experiments on the annealing of dead soft sheet in hydrogen atmospheres — atmospheres in which the nitrogen content was low — sometimes gave results which showed perfectly stable steels (that is, steels whose tensile strength decreased constantly as the temperature was increased) and at other times results which were erratic. In the vast majority of cases considerable improvement in the strain aging, as measured by the high temperature tensile test, resulted. These annealings were performed in a tubular furnace, and before the power was turned on and the "hydrogen anneal" started, a period of about 30 min. was allowed for flushing with electrolytic hydrogen.

It was finally realized that the erratic results were due to small amounts of nitrogen remaining in the furnace, since a considerable time and a heavy flow of hydrogen would have to be employed to dilute the nitrogen to low percentages in the annealing atmosphere within the time usually employed. (These first experiments occupied an interval of about seven hours.) Thereupon the cold quartz tube containing the steel specimens was first filled with water. The water was then displaced by electrolytic hydrogen, to guarantee an amount of nitrogen (0.050%, approximately, by volume) not above that ordinarily present in cylinder hydrogen made by the electrolysis of water.

Thereafter, the results after hydrogen annealing at given times and temperatures were reproducible on any one gage of sheet. One such result will be recorded in the table below, in which the specimens were brought to 1380° F. in 34 min., held at 1380° F. for 6 hr. and cooled to 800° F. in 40 min., during which time electrolytic hydrogen was allowed to flow through the furnace. At 800°, upon cooling, the hydrogen was turned off, the entrance and exit to the furnace tube were sealed, and the whole cooled to room temperature in about five hours. By decreasing the time at annealing temperatures or by decreasing the annealing temperature, while holding the annealing time constant, the increase or decrease in tensile strength at a given testing temperature could be held to any desired value.

In other words, something was either going into or coming out of the steel (when held above the critical in a stream of electrolytic hydrogen), that has a definite effect on the

Stabilization of Sheet Steel by Annealing in Hydrogen

Steel	Dead Soft; Box Annealed			After Annealing in Electrolytic Hydrogen at 1380° F. for 6 Hr.		
	Temp. of Test	Tensile Strength	% Elong. in 2 In.	Temp. of Test	Tensile Strength	% Elong. in 2 In.
20-g. rimmed	Room	43,490	42	Room	38,625	47.5
	420° F.	54,950	19.5	430° F.	31,040	38.5
	Diff.	*+11,460*	*−22.5*	*Diff.*	*−7,585*	*−9.0*
18-g. rimmed	Room	45,795	43.5	Room	39,920	44.5
	435° F.	56,965	18.0	425° F.	34,510	25.0
	Diff.	*+11,150*	*−25.5*	*Diff.*	*−5,410*	*−19.5*

strain age embrittlement of the sheet. In view of the fact that a little nitrogen, entrained in the hydrogen, would upset these results, and in view of our former proof that high nitrogen steels are very susceptible to strain aging, we made a first assumption that the action taking place during the hydrogen anneal was a passage of nitrogen out of the solid steel.

Thermodynamic calculations based upon the best free energy data available have been made. It has been necessary to assume that the activity of nitrogen in the steel is equal to the mol fraction of Fe_4N, and this assumption should not lead to error in the degree of magnitude of the result because of the low percentages of nitrogen present in basic openhearth steel (0.005% approx.). Such computations predict that at 1430° F., with the partial pressure of hydrogen in the annealing atmosphere at one atmosphere, 0.10% nitrogen in this gaseous environment by volume is at equilibrium with a steel containing 0.005% nitrogen. With nitrogen in the annealing atmosphere above this value a steel with 0.005% N_2 will absorb nitrogen. With nitrogen below 0.10% by volume in the furnace atmosphere, a steel with 0.005% N_2 will lose nitrogen. Increases in temperature increase the permissible nitrogen in the annealing atmosphere,

Physical Properties of Two Heats of Ductiloy Containing Different Amounts of Zirconium

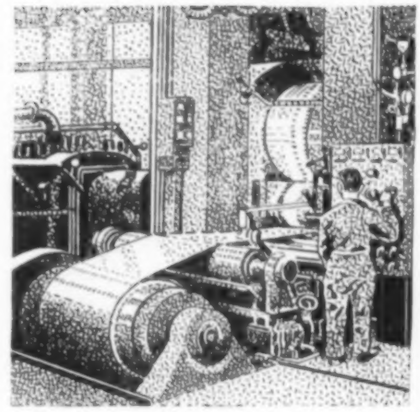
Temp. of Test °F.	Tensile Strength		% Elong. in 2 In.		% Red. of Area	
	Zr. 0.09%	Zr. 0.14%	Zr. 0.09%	Zr. 0.14%	Zr. 0.09%	Zr. 0.14%
−125	84,500	90,750	38.8	36.0	69.4	66.5
75	72,000	81,000	38.8	36.7	74.3	69.0
400	67,500	74,000	32.2	35.9	74.5	70.5
500	67,500	74,000	33.0	34.4	72.9	70.7
600	70,000	73,750	30.0	31.3	71.4	68.8
700	..	75,250	..	29.6	..	66.1

All standard 0.505-in. specimens.

while decreases in pressure decrease the permissible range of the hydrogen-nitrogen ratio in the atmosphere.

From the foregoing results, it is obvious that studies of the Fe-N system must define the partial pressure of nitrogen in the gaseous phase, for otherwise studies of the phase-temperature relationships in the steel itself will be inconsistent and of no definite physical meaning insofar as equilibrium is concerned.

It is well known that nitrogen can be controlled in the openhearth melt by the use of elements which react with nitrogen, such as aluminum, zirconium or titanium. These, in the main, do not reduce the quantity of total nitrogen, but change it to inactive forms. In the case of titanium or zirconium, these inactive forms can be perceived with the microscope as nitrides of their respective metallic elements. These elements are strong deoxidizers as well as nitride formers, and their use produces killed steels.



The effect of zirconium on blue brittleness phenomena is illustrated in the data of the last table. These tensile specimens were 0.505-in. standard pieces, machined from a 1-in. hot rolled round, from two separate heats of our low alloy, high tensile steel known to the trade as Ductiloy, and described briefly in "Critical Points", Metal Progress, April 1940, page 429. One heat contained 0.09% zirconium and the other 0.14%. The higher physical properties of the latter are due to somewhat higher carbon content. From the data in this table, it is apparent that both steels are quite stable against blue brittleness, the higher zirconium heat being somewhat more stable than the lower, but both of them have tensile strengths that slightly decrease (with no maximum) as the heating temperature increases, and the figures for ductility correspondingly also slightly decrease. That these steels, lacking any trace of blue brittleness, are also free from strain aging, is proven by their considerable use where unusual cold forming properties are a prime requisite.

It is significant that the most powerful deoxidizing agents used in steel making are also the most powerful nitride formers. These are zirconium, titanium and aluminum. Each used alone will produce steels stable against strain aging. Each will also, if used in sufficient quantity to fix the nitrogen as inactive compounds, result in killed steels.

A Page for Our Biographical Dictionary

John Frederick Wandersee

An Appreciation by Harry W. McQuaid

THE PROVERB that opportunity knocks once at every man's door was certainly true on the morning of Oct. 17, 1902 when a young man fresh from a Wisconsin farm walked into a small building at 81 Park St., Detroit, and was hired to do odd jobs. After cleaning up the place and lighting a fire in the coal stove the man in charge told him to come back in the morning because "we are going to get started here". Of course he did not know what that really meant; in fact, no one else knew. The man who said they were going to get started was HENRY FORD and the man he said it to was JOHN WANDERSEE, and ever since that time HENRY has been starting things and JOHN has helped to finish them.

What HENRY FORD was starting, of course, was the production of his automobile, and the original force consisted of five draftsmen and five experimental men or machinists, to say nothing of the strong young man to keep the place clean, run errands, and be generally useful. This young man displayed so healthy an interest in everything that was going on that as time went on Mr. FORD gave him a chance to do experimental work, machinist's work and even to serve as purchasing agent.

Ford Motor Co. was incorporated in June 1903 and late in 1906 started to build the light car which became famous as the Model T. Such a tonnage and variety of metals was then being purchased that it was decided a laboratory was needed for metallurgical control and testing. JOHN WANDERSEE was placed in charge, and under the direction of J. KENT-SMITH and C. HAROLD WILLS he delved into the structures revealed in steel by the microscope and learned how to make and interpret photomicrographs. This was real pioneering, and required long hours of study and patient work and proved to be of inestimable value in his development. Within a few months some physical testing equipment was installed and Ford was well started toward the possession of what is now one of the finest physical testing laboratories in America.

Late in 1907 it was decided to provide complete facilities for the analysis of steel and materials and WANDERSEE was again elected to take charge of the new department. This decision resulted in his spending the next three months in the laboratories of the United Steel Co. at Canton, Ohio. Here, with the help of FRED GRIFFITHS, he mastered the technique of the methods then known for the analyzing of metals and alloys. He then purchased the necessary equipment for the first Ford chemical laboratory and by 1908 the control of incoming material was definitely under way, as well as the control of the heat treating and processing operations. Within a few years the continuous furnace made its appearance in heat treating departments, and with the great expansion in Ford production WANDERSEE's position became one of real importance in the world of alloy steels.

At that time practically every important part of the Ford chassis was made from alloy steel. Chromium-vanadium steels were especially favored because of their ease of processing, and series of steels based on the carbon content had been carefully worked out both in plain carbon steel and in the preferred alloy combinations. While JOHN WANDERSEE has been intimately associated with the many developments connected with the evolution of the Ford car, he was in an unrivaled position to develop the relative advantages of various types of steel for car parts. I wish therefore to speak of his important contribution in the processing of the carbon steels higher than normal in manganese.

In spite of the pressure for the use of "alloy" steels, he has successfully demonstrated that proper processing of the carbon-manganese steel will give satisfactory performance in a great many parts. JOHN WANDERSEE was one of the first to realize that, given sufficient carbon to develop the required hardness and sufficient manganese to permit this hardness to be obtained by a carefully controlled quenching in water or caustic solutions, satisfactory parts could be made from the so-called carbon steels in the largest commercial quantities. In parts ranging from axle shafts in the smallest Ford model to large cranks for giant presses, the careful selection of the proper carbon-manganese combination, together with the correct processing, has demonstrated that satisfactory if not superior properties can be developed in

this type of steel. Furthermore, in the oil hardening grades WANDERSEE was one of the first to realize the advantages of the straight chromium-manganese steel having a proper balance of manganese and chromium, and in his connection with Ford Motor Co. has had a hand in the development and processing of these steels in great quantities.

It is doubtful if any single individual has been more closely connected with the details involved in the making and processing of automotive steels than has JOHN WANDERSEE in his 40 years with the industry. There is probably no other name which is so well known to the supplier of steel. To those of us who have had intimate contact with him, the association has always been illuminated by JOHN's common-sense viewpoint and his grasp of the details of every stage of manufacture. He is noted for his fairness and at the same time for tenacious holding to his beliefs. This firmness of conviction, backed by his long years of experience with large scale production and an almost infinite amount of experimental development, has made it necessary for those who have tried to influence him, metallurgically speaking, to have a full command of all the data and factors involved. Investigations made on thousands of parts at a time have enabled him to determine the practicability of a change speedily, and this has always been his method of judging the advantages and disadvantages of a suggested procedure or new material. In his own way he has amassed a fund of information, based on this type of investigation, which would be hard to equal.

It is characteristic of JOHN WANDERSEE that he is as interested and optimistic as ever in the development of the metallurgy of steel for the Ford automobile, and is actively engaged in the constant improvement in its analysis and its processing.

HARRY W. MCQUAID

Uranium, the End Element

(or the beginning of the end?)

By Martin Seyt

WHEN I READ in the pseudo-scientific Sunday supplement about how one teaspoonful of any harmless stuff like water has enough atomic energy in it to run the mills, factories, steamships, locomotives, automobiles, aircraft and vacuum sweepers of the entire world for 100 years, and then read about the bigger and bigger cyclotrons and other atom-busters that are being built to release this atomic energy, I am vaguely fearful that some day some rash physicist will touch off a snowball reaction that will announce itself to Christendom in an all-consuming, all-shattering eruption, instantaneously reducing the entire planet to star dust, an event noted some thousands of years later by astronomers on the nearest inhabited sphere as a novum rapidly attaining great brilliance but as rapidly fading.

Then it is I get some degree of reassurance from reading my favorite author in the realm of modern physics, Dr. KARL DARROW of Bell Telephone Laboratories, who has unique ability to write about atomic research in a way understandable to the neophyte, explaining, as he goes along, the very special nomenclature, notation, and experimental methods in that realm.

From him I find the comforting fact that when an atom is hit by a fast-moving particle (whether alpha-particle, proton, deuteron, neutron or photon) the result — if any — is a transmutation into a new element no greater than two atomic numbers above or below the original. If these newly created elements (or isotopes thereof) are unstable, the fact is announced by radioactivity, that is, the shooting off of either a positive or negative electron or an alpha particle (helium nucleus). All these reactions conform to the laws of conservation of mass and momentum, and dampen themselves out more or less rapidly. A crude way of expressing it is that it takes a high velocity projectile to knock off a particle, and these particles move too slowly for further damage.

However, something happened about a year ago that again upsets these comfortable assurances. Physics seems to be going as berserk as international morality. Neutrals are vaguely nervous, wondering where lightning is next going to strike and when. [EDITOR'S NOTE: This letter, written before *(Continued on page 712)*

By Max. W. Lightner
Pittsburgh, Pa.

Openhearth Operators Discuss Advances in Steel Making Methods

THE Openhearth, Blast Furnace and Raw Material Conference held in Pittsburgh in April by the American Institute of Mining and Metallurgical Engineers was by far the best attended and the most interesting meeting of its kind which has been held. The joint session of men interested in blast furnace smelting and openhearth refining clearly indicated that each is more fully realizing the problem of the other, and a combined effort is being made to produce steel which will meet the consumer's exacting requirements at the lowest cost.

Good Iron and Its Production

The advantages to be obtained in openhearth operation by the use of low silicon iron were clearly brought out. The refining of 0.60 to 0.80% silicon iron results in less time of heat, less fuel per ton, less lime and spar to control the sulphur and phosphorus, less damage to the banks and decreased refractory cost, and permits the use of a higher percentage of iron. In many shops the practice is to use a flush slag to eliminate some of the SiO_2 from the system, so that less lime need be charged and the slag volume may be held at a minimum. One speaker pointed out that there is a loss of MnO and FeO in the flush and the yield will be lower on flush heats. Slag control is also more difficult because the higher the silicon in the iron the larger the flush should be in order to melt with the same slag condition. Definite control of the size of the flush slag is rather difficult.

It is generally considered that low silicon iron from the blast furnace is accompanied by high sulphur. Sulphur is a particularly troublesome element in the openhearth; on account of this, iron is usually produced of higher silicon and lower sulphur. One speaker felt that the production of low sulphur iron by a correspondingly increased silicon is entirely nullified in the openhearth. It is necessary to have free CaO in the slag to lower sulphur. Consequently when the silicon is high more CaO is necessary to flux the SiO_2 formed before an excess amount of CaO is obtained.

Two methods for supplying low silicon iron were discussed. Many blast furnace plants are now adding 5 to 6% scale to the runner at the blast furnace. One speaker reported that the silicon loss is 50% and the manganese loss is 40%. The reaction between the silicon and the oxide is exothermic, thereby raising the temperature of the metal. It was reported that the reaction is quite violent and should not be done in a confined place. The slag produced contains approximately 15% FeO, 32% MnO and 40% SiO_2, is quite viscous, and in all cases is skimmed off before the iron is poured into the mixer. It was further stated that there had been no detriment to the quality of steel made from iron to which scale had been added.

Another means of producing 0.60 to 0.90% silicon iron with 0.050% maximum sulphur is by increased blast temperatures. Charts from a large operation were presented which showed that as the blast temperatures were increased over a period of several years, the fuel ratio decreased, production increased, and a lower

silicon iron of greater uniformity resulted.

One operator who uses a high scrap charge in the openhearth stated that he prefers iron of the following analysis: Si 0.95 to 1.05%, Mn 1.80% to 1.90%, S 0.020% maximum, P 0.20% maximum. He described this iron as an all-purpose iron, being used in a shop where a variety of grades of steel are made. The restricted range of silicon between 0.95 and 1.05% is desirable to give the most dependable melt-carbons, and permits the proper charging of limestone so that corrective additions need not be made later. Manganese in the range of 1.80 to 1.90% is desired to give a more active heat and a higher residual manganese. Phosphorus not over 0.20% is desirable as it will require less limestone in the charge, will not necessitate any special precaution to prevent phosphorus reversion on killed heats, and will readily make the desirable low phosphorus on sheet steels. Sulphur is desired below 0.020% for making deep drawing steel.

A very enlightening paper was also presented in defense of the blast furnace operator, and the speaker mentioned some of the reasons why consistently uniform iron cannot be produced from day to day. The operation of a blast furnace depends upon the opinion of the personnel operating the furnace; guessing is an essential factor and the operators must guess right. Furthermore, the blast furnace is not an hour-to-hour proposition, but guesses must be made in anticipation of what conditions will be eight to ten hours hence. Should a furnace be running "sour" and an adjustment be made, it requires time to know what will be the effect. The burden of a blast furnace is continually moving downward and the gases upward. Varying amounts of ore may be blown out of the top, and hanging and channeling often occur with resulting hot spots so that the furnace is thrown out of balance. Chemical analyses were shown in this paper indicating the fluctuations in the raw materials. Ore analyses vary in acid oxides as well as in iron, phosphorus and manganese. Coke analyses also vary, and as the ash content increases, the carbon content decreases. The furnace will run colder on high-ash coke, the acids in the slag will increase, and the iron will be higher in sulphur.

It was reported that the "active" type of mixer is now being used extensively in Europe, especially in England. These active mixers are usually revamped mixers of the ordinary type of 500 to 600 tons capacity, and fired regeneratively with blast furnace gas. The iron is held in the mixer from 12 to 24 hr., depending upon the size. The fuel requirements are from 800,000 to 1,250,000 B.t.u. per ton of iron. The following percentage reductions of the metalloids are claimed: C 10%, Si 60%, S 25% to 40%, P 10%, Mn up to 50%.

There was some discussion about the best temperature at which to charge iron into the openhearth. One reported that automatic control equipment is installed on the mixer to keep the temperature within definite limits. It was believed by another that the best temperature was between 2400 and 2450° F. The general consensus was that the hotter the iron when charged, the faster the furnace would work.

Refractories (and Inclusions)

There is no definite evidence to show that pouring pit refractories are the source of inclusions in killed steels. However, some refractory particles may be trapped in the skin of the ingot, and result in a bad surface, from "washing out" of nozzles and from sand in the ladle pocket. One speaker stated that when inclusions from ladle refractories are found they usually occur in one ingot or in part of an ingot, whereas inclusions that are deoxidation products occur throughout the ingots of a given heat. Clay plugs, used in the bottom of big-end-up molds, are not a source of inclusions in the ingot, because they show little or no wear after use. Most metallurgists were of the opinion that no inclusions which originate from the clay hot top on top poured ingots are encountered in the steel. However, one speaker had found such inclusions trapped in the tar coating on the mold and eliminated his difficulties by washing the molds.

Methods which may be used for identification of inclusions consist of the hot acid etch test, the petrographic microscope, the X-ray for crystalline materials, and vacuum extraction chemical methods.

Various materials are now being used to improve runner linings. Some shops are using basic linings, but the cost is quite high. One reported that linings made of "Lumnite" and crushed basic brick-bats were giving good results without excessive costs.

Magnesite nozzles which do not cut out are used both in this country and abroad. In order to overcome the slow pouring rate which results from loss of heat in the ladle at the finish of

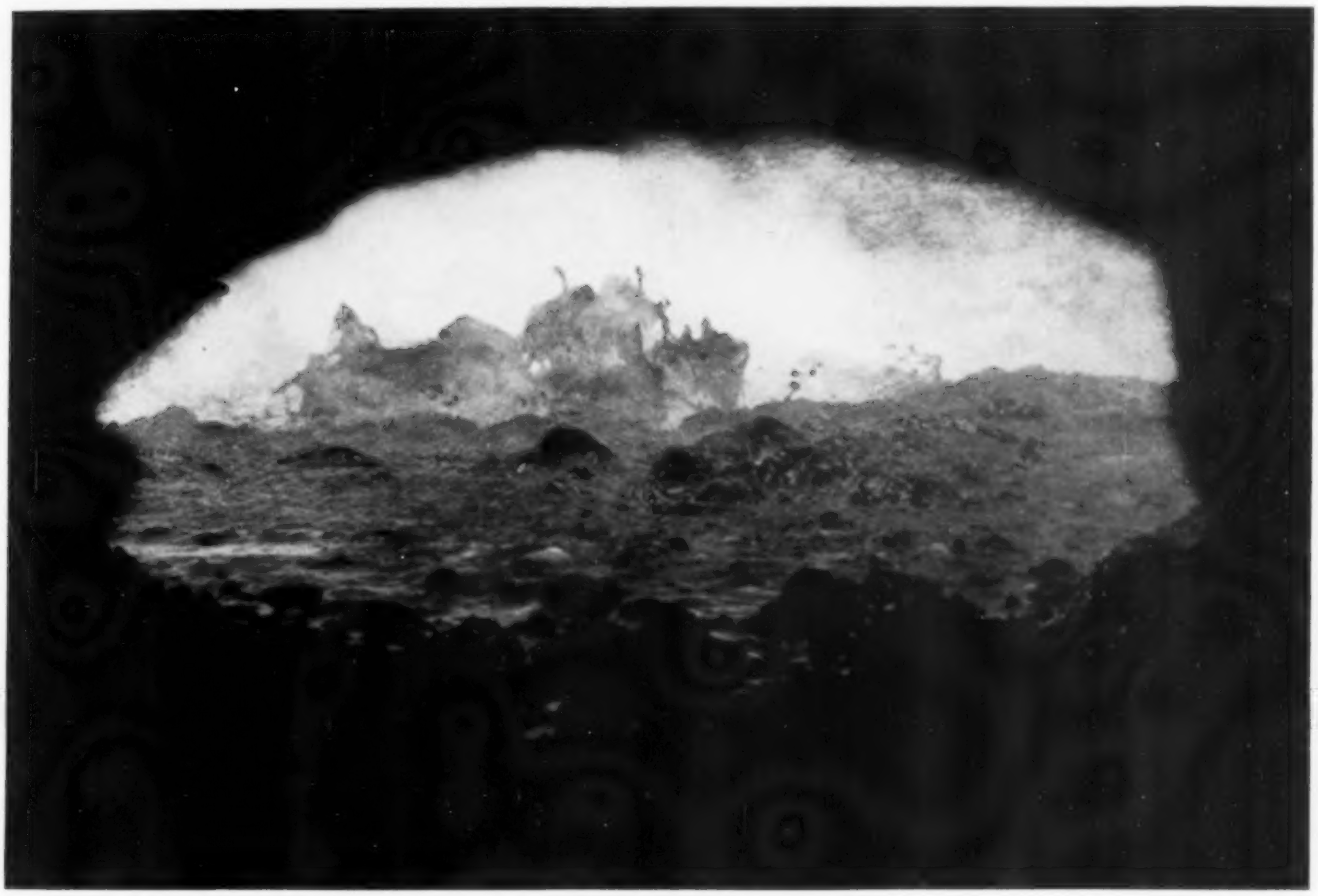
pouring, two methods are favored: In the first the ladle is equipped with two stopper rods and set with a large and a small nozzle; the first half of the heat is poured through the small nozzle, and the latter half is poured through the large nozzle. In the second method a rigging is attached beneath the ladle and the two nozzles are set in series; after the rate of pouring becomes sluggish, the smaller nozzle is removed and the pouring is finished through the larger nozzle.

There was quite a lot of discussion on the use of "Ramix" in openhearth furnaces. Excellent results are being obtained on a number of electric furnaces, and several operators reported its use as a patching material in the openhearth. The statement was made that it has been used to patch holes 12 to 15 in. deep, and charging was started within an hour. It was also stated that a 100-ton openhearth with a Ramix bottom was giving very good results.

Several operators also reported that chrome ramming mixes had been used satisfactorily for bottoms over a period of several years.

Construction Details

An interesting discussion followed the description of the basic roof on a Canadian copper refining furnace which had given remarkable service. The refractories people in this country feel that they can supply the trade with basic brick equal to those used successfully in roofs in Europe, but that their use will require changes in furnace design to take care of the difference in physical characteristics of the basic brick. New skewback designs or suspended roofs were indicated. Other items, such as the life of furnace checkers, would also have to be considered in determining the economics of a basic roof installation, for continuous operation is most desirable for obtaining maximum life from one of these roofs. Quite a few of the companies represented had tried basic brick patches fairly successfully, chiefly over the tapping hole and along either back or front skewbacks. Where these patches are over three feet wide, similar difficulties are experienced as would be had with an entire basic roof.



There She Boils!
View through open door into openhearth furnace, from a movie by Carnegie-Illinois Steel Corp.

Teeming a Large Ingot, as Photographed by John P. Mudd for The Midvale Co.

Some advantages are to be gained from streamlining furnaces but most plants, especially the older ones, were limited in the amount of changes that could be made to the furnaces. Little was said of the advantages and disadvantages of single and double uptakes. Some plants are forced to single uptakes because of cramped conditions at the furnace ends. Cutting away of uptakes is caused chiefly by *(a)* the sudden change of direction of the gases passing from port to uptake; *(b)* overfiring the furnace; *(c)* excessive gas velocity caused by insufficient cross sectional area in the uptakes. One operator claimed to have had some difficulty with the Crowe pockets on the first runs, as the slag seemed to block up at the time of a backwall repair. By making slight changes in design he expected to overcome this difficulty. Another stated that Crowe pockets were operating quite satisfactorily with savings

in fuel and improved furnace operations. It was stated that the Smalley checkers are very easy to clean, while the Loftus type is rather difficult to clean and slowed down the furnace toward the end of the run.

A stud-tube, water-cooled door was described. Approximately seven months' service had been obtained from one door, and a furnace had been put in operation with all doors of this design in addition to a stud-tube bulkhead construction. This furnace was operating satisfactorily with 90 heats already out. Successful use of arch-less door frames was reported at various plants. Some have installed water coolers along the bottom flange of the skew channels which prevent sagging of the roof when frames are changed. Back-skew channels are also water cooled at various plants.

Operating a 1940 Openhearth

Checkers are cleaned periodically, usually every two weeks during the campaign, by the use of compressed air. During a major repair the upper five or six courses of brick are usually replaced.

For the drying and closing of tap holes, single and double burnt dolomite and raw dolomite are in use. In most cases, single burnt dolomite is used for facing the tap hole, and "695" is used for piping it. The oxygen lance is used most extensively for opening tap holes.

Hot houses, or ovens for retaining the heat in molds and for warming up cold molds, are now in use in at least one plant. Most operators still use gas burners for warming cold molds.

Dolomite machines are in use in some plants and a saving of time in making up the bottoms is claimed. Others have discontinued their use due to the build-up of banks. In shops where the majority of heats are of medium or high carbon grades, the furnace is given a washout periodically, wherein several low carbon heats are charged after every 20 to 25 heats of high carbon to prevent the bottoms from becoming too high.

Chrom-X is now being used extensively in some plants to make chromium steels. As noted in the "Critical Point" on page 673 this is a mixture so compounded that it will react exothermically to produce molten high carbon ferrochromium. It was reported that 95% recovery of chromium is being obtained when the addition is made in the ladle to form 1% chromium heats.

The openhearth shops now being constructed are practically all equipped with automatic control of one type or another. In a shop equipped with all types of automatic controls the operator reports a saving in fuel with less time of heat and increased tons per hour. He believes that pressure control is of most value, a fuel saving of 1 to 1.5 gal. per ton is attributed to it. Next in value is checker temperature equipment, and air-fuel ratio control is of least value. Others reported increased roof life due to roof temperature control, and fuel savings due to draft control. There were others who were of the opinion that manually operated furnaces gave about the same performance as automatically controlled furnaces. The general opinion was that there is a saving in time of heat, fuel and refractory cost by the use of automatic control, but it is very difficult to determine the benefits to be obtained from any one control.

The carbanalyzer is now being used extensively with very good results, as its accuracy is considered to be within 0.01% carbon. This machine may be used on the openhearth floor, as it is not affected by heat or cold. However, it is necessary to obtain good test pieces, because if the test is not straight or if it has fins, the results will be erratic. Manganese residuals in the range 0.06 to 0.35% do not affect the results, but nickel or molybdenum residuals will probably cause the carbon results to be erratic. One reported that he uses the Leeka process for carbon determination. It requires only 3.5 min. from the time the test is received, and the results are as accurate as determinations by combustion.

Strangely, the most discussed subject in the operating session was on the proper heating of steel in the soaking pits. It was emphasized that the heater should know what types of steel he is heating. Ingots with a thick skin can be heated much more rapidly without danger of exposing blowholes than ones with thin skin. Heating cycles should be enforced on alloys and higher carbon steels to prevent cracking. Ingots should be expedited from the openhearth to the mill and should not remain in the pits after they are up to temperature and ready to roll. The design of the old type pits and the inability to heat ingots properly in plants of limited heating capacity were noted. In one plant, photographs of ingots which crack during rolling are taken by the roller on the pulpit, and drafts are reduced when an ingot starts to crack.

Quality

A discussion of slag control, including the proper methods and the benefits which might be expected, indicated that this subject continues to be of considerable interest to the open-hearth metallurgist.

One speaker discussed the proper method of controlling a heat of quality killed steel. The heat should be charged so that when it is melted there is a deficiency of lime in the slag. The slag in the refining period should have a "V" value of 2.2 to 2.5, in which range slag pancakes may be successfully used to estimate the basicity.* The primary function of the slag during this period is the proper elimination of phosphorus. When the "V" value exceeds 2.5, the slags become too viscous and the FeO in the slag increases. When too much lime is charged the heat will melt with a slag having a high "V" value, and will necessitate the adding of SiO_2 so that the FeO in the slag does not become too high. This results in an increased slag volume and a slower working heat. It is desirable to have a fast working heat and arrive at the tapping carbon as soon as possible to keep the FeO in the steel low and reduce the amount of furnace deoxidation. For killed steels a "V" value of 2.5 to 3.5 at tapping time is desirable, and burnt lime is added during the last hour to obtain the proper basicity. The amount of lime added will depend upon the nature of the deoxidation and the length of time the deoxidizer is to remain in the furnace before tapping.

Another speaker on slag control emphasized the fact that the control should be such that it will give the most economical practice. If the control means increased time of heat, then it must be balanced against any benefits which may be obtained from its use. The slag should be controlled to eliminate phosphorus and sulphur from the metal without undue loss of iron into the slag and without the use of excessive amounts of lime. The time of working the heat should be lowered by reducing the amount of lime charged, and the net result should be a standardization of the oxidizing conditions at tap in order to permit a saving of deoxidizers. The primary variable as far as slag manipulation is concerned is the silicon content of the charge, and iron of a low and uniform silicon content should be made in the blast furnace. The speaker believed that all corrective additions should be made during the melting period, because heavy additions of lime during the refining period are not desirable. It was recognized that the slag and metal are not uniform before the heat is melted, and as a result it is necessary to take numerous tests to obtain an idea of the necessary additions. The practice is to rely largely upon the trained eye of the melter foreman, for which no substitute has yet been found. Frequent determinations of the FeO and SiO_2 content of the slags and the sulphur content of the metal are made as a basis for lime additions, and the physical characteristics of the slag are carefully noted. It was stated that the viscosimeter is a useful tool for determining slag characteristics during the melting period, but in later stages of the heat when the slag is more basic the slag pancakes and color tests are of more value. Slag control should be simplified so that it can easily be handled by the men on the furnace with as little "disturbance" as possible from metallurgists.

The "bomb type" test mold is now being used extensively to obtain metal samples for FeO analyses and the consistency and reproducibility of results seem to be definitely assured. Contrary to the belief which has prevailed among metallurgists heretofore, carbon is now recognized as a better indicator of the FeO content of the metal than the FeO or total Fe content of the slag. It is also true (especially when the carbon is below 0.10%) that with a higher basicity, a higher ratio of the FeO in the slag to FeO in the metal exists. The residual manganese does not correlate with the FeO in the metal. It was the general opinion that a higher manganese residual will result in cleaner killed steel, because a high MnO in the steel accompanies a higher residual manganese and will act as a flux for SiO_2 particles.

In the production of the best quality killed steel the heat should be worked rapidly, but no ore additions should be made within one hour of tapping time. Silico-manganese is used extensively as a furnace deoxidizer and good results are being obtained.

Many plants are now using shot aluminum in preference to aluminum piglets or ferro-aluminum as a ladle deoxidizer. The methods for adding aluminum should be carefully studied so that it is properly added to the stream in the runner and not lost in the slag.

*"V" value refers to the CaO/SiO_2 ratio of a slag, correcting the CaO in the analysis for the amount figured to combine with the P_2O_5 as tricalcium phosphate $3\,CaO \cdot P_2O_5$. The formula is

$$\text{"V"} = (\%\,CaO - 1.19 \times \%\,P_2O_5) \div \%\,SiO_2$$

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Improving the Durability *of large* Industrial Gears

AN ARTICLE by the present author entitled "Industrial Gears for Large Transmissions" was printed in METAL PROGRESS last December. It outlined their service requirements, types of failure to be guarded against, types of steels used and their desired physical properties. Let us suppose that decision has been made as to these factors; the metallurgist must then decide upon the manner by which these physicals are to be secured.

Heat treatment of gear materials assumes special significance because the ability of gears to carry a given load is directly related to the accuracy of the tooth dimensions. Therefore with increasing accuracy, the greater is the proportion of the physical properties which can be utilized for "pay loads" rather than "self-generated loads". Quenched and tempered gears have frequently been unsatisfactory due to uncorrected warpage from heat treatment, and it has been repeatedly found that gears of higher hardnesses with the inherent higher physicals have failed to carry loads being transmitted by gears of lower hardnesses but with greater accuracy.

Therefore every precaution is used to minimize distortions in gears heat treated after cutting or to increase the accuracy by improving the machinability of materials to be cut after the blank is heat treated.

The principles of the heat treatment required to produce desired strength to resist bending stresses are well known. Therefore, these methods do not demand a detailed discussion. The effects of grain size, alloy and carbon contents, quenching and drawing temperatures, preliminary treatments, etc., are thoroughly treated in the general metallurgical literature.

Fundamentally, there are but two methods of obtaining physical properties (specifically hardness) for increased durability of the contacting gear tooth profiles. These are *(a)* surface hardening and *(b)* full hardening.

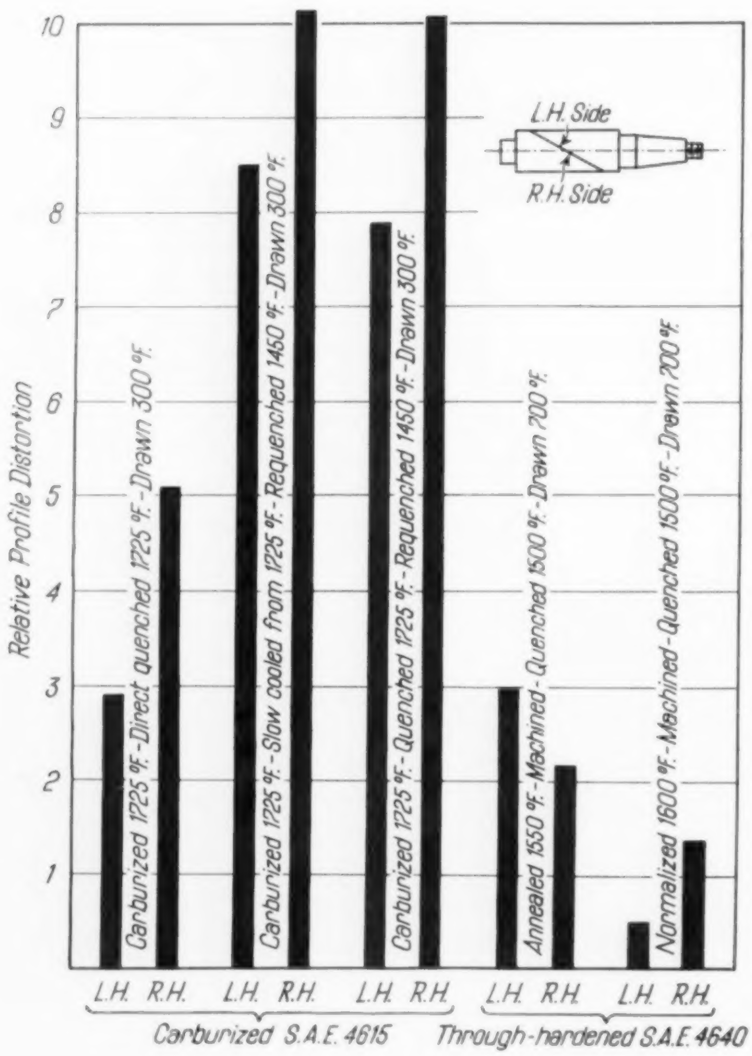
Surface or profile hardness is obtained by means of

1. Carburized cases
2. Light or activated cases
3. Nitriding
4. Flame hardening

Carburized Cases: The fundamentals of carburizing practice have been rather thoroughly discussed in the literature since 1920 and require but little elaboration in this place. Reference should be especially made to the papers and discussion at the symposium on carburizing held at the 1937 convention in Atlantic City and published in *Transactions* as well as in a separate volume.

Metallurgically, the choice of steel and the carburizing treatment for industrial gears is largely influenced by the application and the production facilities available in the shop doing the work. For small gears, plain carbon steel is satisfactory. Heavy loads, high speeds, excessive shocks, and especially minimum heat distortions demand an alloy steel.

In the carburizing process, care must be exercised to have a uniform, well diffused case. All indications of an excessive cementite network should be avoided. The gears may be



Relative Profile Distortion of Gears, Cut and Then Hardened in Various Ways

either pot quenched, or cooled and single or doubled quenched, followed by a draw. The exact procedure is dependent upon the steel analysis and nature of the gear load. Preference is given to the process resulting in minimum distortion (usually the direct pot quench unless exceptional core properties are desired).

Light Case: A thin case of 0.008 to 0.015 in. is sufficient in some applications to provide surface durability, particularly where abrasion will occur in service.

The usual light case is obtained by means of an activated bath or special gas, and is high in carbon and nitrogen.

Nitride Cases are very high in nitrogen and produce the hardest possible cases. Nitrided cases have been successfully used for aircraft gears, and pump gears handling abrasive compounds. The process results in fairly low distortion but the special steel, long treating period and complicated equipment increase the cost above that which can be absorbed by most industrial applications.

Flame Hardening is used when it is desired to surface harden gears of a size larger than can be economically handled in carburizing equipment, or when the size or shape prevents a full quench. Flame hardening is also called torch hardening or Shorterizing and, as well known, consists of passing a voluminous oxy-acetylene flame from special burners across the face to be hardened. This heats the surface layers of the steel above the critical temperature. Rapid cooling to harden is then effected by the natural conduction of heat into the cold underlying mass of unheated metal, usually supplemented by a water jet following closely on the heels of the heating flame.

The process has been described or commented upon frequently in the literature. Reference may be made to the following 1939 issues of METAL PROGRESS: April, page 372; July, page 49; August, page 141; October, page 574. As now practiced it inherently violates the following principles of good heat treatment in furnaces:

1. Slow and uniform heating above the critical temperature.

2. Complete diffusion and solution of the carbides, obtained by a proper "soaking" period.

3. Quenching at a rate which will give the desired transformation without likelihood of quenching cracks or surface checks.

4. A proper tempering treatment to remove brittleness and to relieve the internal quenching stresses bound to be present.

The process is therefore properly limited to gears which cannot be otherwise hardened. This limitation is also dictated by costs; it will usually be found cheaper to fully quench and temper a gear which can be so treated than to flame harden the profiles.

The following precautions must be rigidly observed if acceptable flame hardening is to be done:

1. The rate of heating must be carefully determined for each analysis of steel and each tooth pitch. The main defect of the flame hardening process at the present time is the lack of instruments and technique necessary to control the maximum temperature.

2. Complete solution of all the structural phases is required at the quenching temperature. To aid in obtaining diffusion and full solution, the steel must be refined by a quench or normalizing treatment previous to flame hardening. Gear steels flame hardened in the "as cast" or "as forged" condition are certain to be disappointing.

3. The cooling rate should be regulated by a proper choice of the quenching medium. There is no logical reason to specify or to use a cold water quench for all flame hardening applications, when an air or warm water quench will be found satisfactory for many requirements, with a substantial reduction in the danger of forming quench cracks or checks.

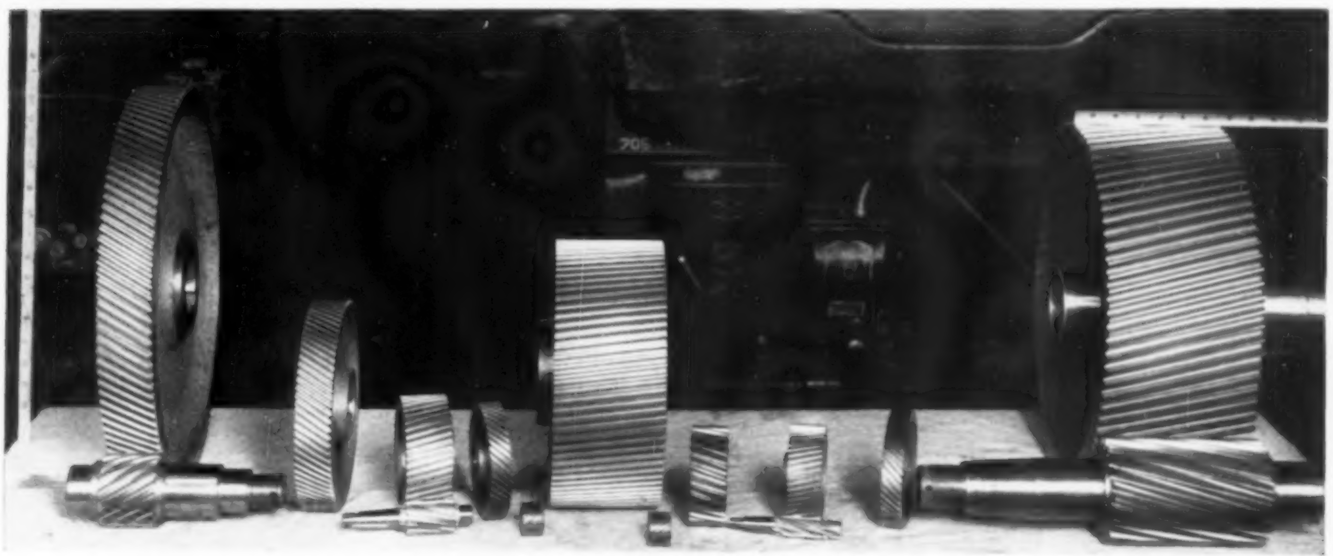
4. A flame hardened gear should be tempered at 300 to 600° F. immediately after hardening. No competent gear metallurgist would think of placing an "as quenched" gear in industrial service; therefore, it is wholly illogical to expect a flame hardened gear to perform properly without a tempering or stress relieving treatment.

The flame hardening process at the present stage of development should never be used for pitches finer than 3 diametral pitch. Carbon in the steel should be within the range of 0.30 to 0.45%. Alloying should be conservative. Maximum hardness should be obtained at the pitch line with the hardness tapering off towards the tip and root.

Because of the high internal stresses and general abuse to the steel, flame hardened gears have a lower strength and durability than full hardened gears, and decidely lower capacities than casehardened gears. Certain prominent foreign gear manufacturers rate flame hardened gears from 25 to over 35% lower than full hardened and casehardened gears of comparable hardnesses. Research has indicated that high internal stresses acting in conjunction with localized distortion are largely responsible for the de-rating.

A major portion of the power transmitting gears for industrial service are fully hardened (or through hardened) either before or after the teeth are cut.

Hardened After Cutting: Small gears in automotive, aircraft, machine tool and small gear reducer applications are often heat treated after cutting. The advantage lies in securing hardnesses above the machinability range at low cost. These direct hardened gears have a 0.40 to 0.55% carbon content with emphasis placed upon such hardening alloys as chromium and molybdenum, with nickel or vanadium as toughening agents when required. To obtain a file-hard surface, it is usually necessary to acquire a light case by heating in a salt bath or a prepared atmosphere.



Gears, Small to Medium Size, Cut After Heat Treatment to Insure Accuracy

N. E. Woldman has made a thorough study of the machinability of these steels in relation to the structure. According to his report to the American Gear Manufacturers Asso. in September 1937, the best gear cutting for S.A.E. 3250, S.A.E. 4350 and S.A.E. 6150 resulted with the laminated pearlite obtained by annealing above the upper critical temperature. This microstructure, however, produced the greatest distortion during heat treatment. Minimum distortion was obtained by a long spheroidizing anneal at or just above the lower critical temperature.

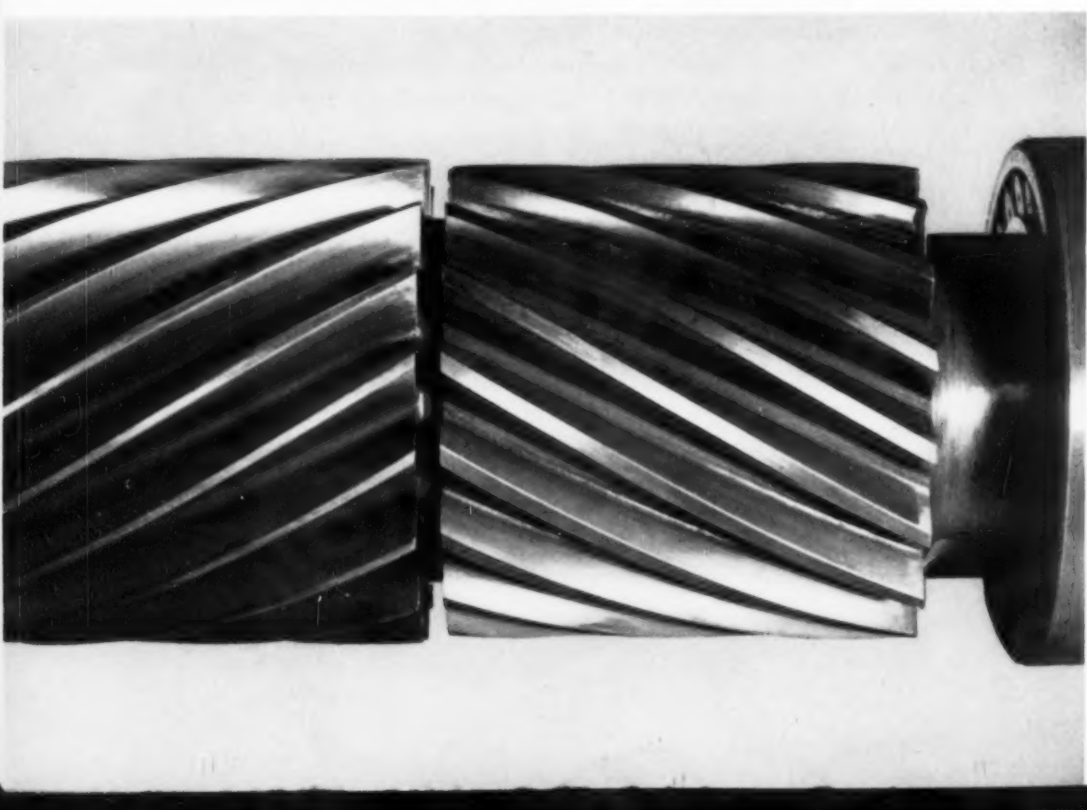
As might be supposed the principal disad-

vantage of heat treating after machining is the change in shape and principal dimensions during the quench. Some heat treating practices are more objectionable than others in this respect, as can be seen from the inspection of the diagram on page 654. Few industrial gears will stand the cost of finish grinding to correct for heat treatment distortions.

Gears Heat Treated Before Machining: In the preponderance of commercial gears used for speed reducers, steel mill units, high speed turbine reduction sets, pump drives, and open gear sets, the load carrying capacity, smoothness of operation and noise level are primarily dependent upon the accuracy, precision and finish obtained. These requirements mean that no errors may be introduced by heat treating operations performed after cutting. Therefore, such gears are cut *after* heat treatment. Special attention is given to factors which reduce distortions due to machining strains, atmospheric conditions and handling. The degree of accuracy obtained is determined by the cutting equipment, experience and technique of the gear manufacturers.

The carbon content for gears cut after heat treating lies between 0.30 and 0.60%. The lower values are used for small sections or alloyed steels, the higher values for larger sections. The alloys selected are determined by the contemplated service of the gears and are limited by the machinability rating. For ordinary commercial pinions, the maximum hardness for economical machinability is about 320 Brinell. Special steels with controlled sulphur and grain size are used for production machining with hardnesses of 320 to 400 Brinell.

Helical Pinion, Right Side Cut to Old Standard Contour and Left Side Cut to Improved Tooth Form, and Run in a Large Speed Reducer to Determine Relative Performance. Note failure of teeth from pitting



Whenever possible, the blanks are liquid quenched and tempered to secure the maximum refinement and physicals for a given hardness. Large or complicated sections, for which liquid quenching is hazardous, may be normalized or annealed. A normalized section should be specified with conservative hardnesses in order to maintain satisfactory ductility.

It is customary to use a pinion which is somewhat harder than the gear. This gives a better wearing combination. It is desirable to specify a heat treated pinion regardless of the condition of the gear.

Too much attention cannot be given to the mechanical design of gears cut from heat treated blanks, and to their manufacturing processes. The proper tooth proportions and degree of accuracy have an important influence upon capacity, as illustrated in the adjoining photograph. Two helices of different tooth proportions had been cut on the same pinion in order to eliminate all variables except that due to proportions. The old standard tooth is identified by the pitting which occurred under identical loads successfully carried by the newer improved tooth form on the other helix. These new forms had been developed by The Falk Corp. after considerable fundamental research.

Some Theoretical Considerations

It seems pertinent to discuss the theoretical considerations which modify or determine the selection of a steel for a particular gear.

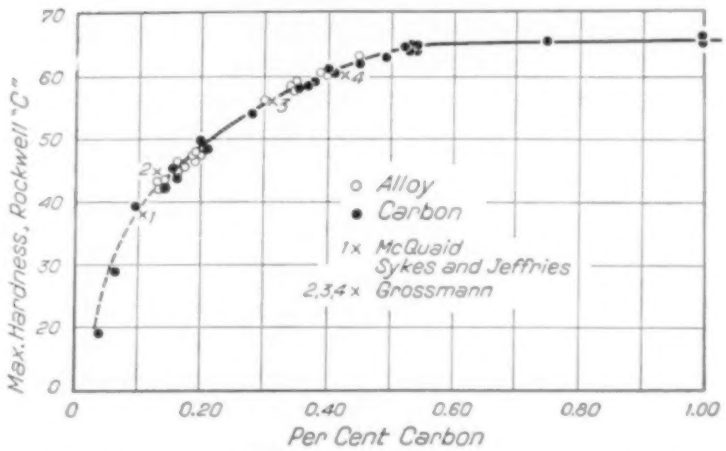
The actual physical properties attained by metals are determined by the circumstances surrounding the application. The variables present which affect the properties of gear materials are:

1. Stress distribution (or stress concentration)
2. Speed of load application
3. Impact
4. Temperature
5. Lubrication
6. Surrounding atmosphere

For a thorough understanding of the principles of gear metallurgy, one must study the effects of these variables upon such fundamental properties of materials as:

1. Tensile properties
2. Hardness
3. Endurance
4. Impact

Tensile Properties: Sharp fillets reduce the load carrying capacity under tension. An increase in the velocity of stress application also increases the tensile and yield values. At very high velocities conditions change; H. C. Mann of Watertown Arsenal has shown *(Proceedings* of the American Society for Testing Materials, 1936-II, p. 85 and 1937-II, p. 102) that the tensile impact resistance remains practically constant until a certain "transition velocity" is reached, after which the tension impact resistance decreases rapidly to very low values.



Tests by Burns, Moore and Archer Show That Maximum Hardness Attainable by Quenching Is a Function of the Steel's Carbon Content Rather Than of Its Alloy

The higher the temperature of operation (below 300° F.) the lower the ultimate and yield strengths and the greater the ductility factors. At temperatures at which commercial gears operate, the decrease in strength is less than 5% of the room temperature values.

Hardness: The fundamental phenomena of hardenability were thoroughly discussed in a symposium on hardenability conducted by the American Society for Metals in 1938. Of interest to the gear metallurgist is the fact that maximum hardness is dependent only upon the carbon content, regardless of moderate amounts of the alloys present. The relation is illustrated in the above diagram, which probably gives a rough indication of the best durability attainable in gears having the corresponding amounts of carbon in the steel at the tooth surfaces.

The value of alloys such as chromium, manganese, and others, lies in their ability to produce deep hardening with less drastic quenches. At present, much attention is being given the "hardenability" of steels. Caution must be exercised in interpreting the values given for as-quenched specimens, because a tempering operation tends to produce rather uniform hardnesses.

Endurance: It is very important that a satisfactory gear design be secured if the optimum fatigue life is to be obtained. Maximum radii must be used at the roots of the teeth and all stress-raisers such as holes, sharp fillets or deep machine marks must be eliminated. From a metallurgical standpoint, all non-metallic inclusions must be at a minimum; too great a formation of fibers in rolling or forging is to be avoided and flakes or thermal checks must not be present.

For all industrial gear sets, the contact and bending stresses must be kept below the endurance limit. The ratio between flexural endurance limit and the ultimate tensile strength (as determined on small laboratory specimens) is about constant at 0.50 for steel. The endurance limit in shear is about 0.575 times the endurance limit obtained in bending. There is some evidence to show that the first mentioned ratio decreases slightly as the steel's carbon content goes up, being about 0.42 at 0.70% carbon.

For cast iron, the endurance limit in alternating direct stresses (flexural or axial) is about equal to the endurance limit in shear. The ratio to ultimate tensile strength varies from 0.40 to 0.50 depending upon its quality.

For high hardnesses or very brittle materials, it is doubtful whether a true endurance limit actually exists.

An examination of the literature reveals that the endurance limit of standard test specimens is not greatly affected by the speed of alternation. This probably holds true in gear applications except that higher velocities usually add increment loads.

However, shock loads do affect the endurance limit, decreasing the limit as the magnitude of the shock increases. The phenomenon is probably associated with the development of complex stresses after the original fatigue crack has been formed. This factor is important in gear applications, but cannot be accurately computed and must remain a mental reservation when selecting materials. The general difficulty in applying the results of endurance tests to design is illustrated by the recent finding of Oscar Horger that full-sized railroad axles do not have nearly as high an endurance limit as laboratory-sized specimens cut from them.

The temperature of operation seemingly affects the endurance limit. *(See page 696)*

Correspondence

Aluminum Replaces Copper Conductors in Italy and Germany

TURIN, *Italy* — The study of various technical problems connected with the substitution of aluminum and aluminum alloys for copper electrical conductors is of special importance for some European countries like Italy and Germany. On account of local conditions of ore and metal supply such substitution is rapidly extending to practically all types of conductors.

As a result of the extensive practice obtained in this field many important practical principles have been fixed. The solution of most of the associated problems, though concerning only technical details, had its compensations in an important inducement for the general use of the new materials.

Disregarding the skin-effect and the eddy-currents, the figures generally adopted for the ratios of weights and sections of copper and aluminum conductors of equal current capacity (that is, for the same temperature rise) and for equal resistance are as follows:

	Equal Capacity	Equal Resistance
Section	1.38	1.61
Diameter	1.17	1.37
Weight	0.42	0.49

The increase of weight of protective coverings, due to increased circumference of aluminum conductors, is more than balanced by the lower weight of cables except for lead coverings, where the total weights are practically the same. For large sections — above 450 sq.mm., or roughly 1,000,000 circular mils — two cables in parallel are used, instead of a single cable.

For sections under 50,000 circular mils where flexibility is of great importance, and where pure aluminum shows inadequate resistance to repeated bending, satisfactory results are obtained with some aluminum alloys, especially with aldrey (a low Si, Mg, and Fe alloy of Al).

For high voltage cables, where smooth and even surfaces are necessary, cold-drawn aluminum wire has some advantages over annealed, on account of its higher surface resistance to abrasion and scratching. But, on the other hand, the higher elongation of annealed aluminum wire facilitates stranding. It may be said that European practice is not yet fixed on this point. Very good results have been obtained, especially for low and medium voltages, with cables formed over a central wire of larger section, which acts as a flexible core, covered by thinner wires of hard drawn aluminum, acting as a protection against abrasion.

The greatest difficulties in the practical application of the new materials were met at the joints, where practices for aluminum cables are completely different from the normal technique for copper cables. However, a number of devices have been successfully adopted.

The essential point about screwed terminals is the continual deformation or creep of aluminum under steady stress. Extensive and interesting researches on this property of aluminum have been made in the laboratories of the Pirelli Co. in Milan, whose results have confirmed the necessity of introducing an elastic element into the joints, capable of compensating, automatically and continuously, for the plastic deformations of aluminum. These studies have also fixed the basic design conditions for the elastic elements (usually disk-springs) to be used in each case, taking also into account normal variations of temperature.

Good results are also obtained with strongly compressed cylindrical coupling sleeves, a

design studied especially by the South German Cable Works in Mannheim.

Serious troubles have been met with soft-soldered joints on aluminum cables, so that this type of joint is now seldom used in Europe. On the contrary, excellent results are obtained with the autogenous welding of aluminum and aluminum alloy cables. Usually no fluxes are used. When a suitable flux is added, great care must be taken for its complete elimination from the welded joint, in order to avoid its subsequent chemical action on the metal.

Equally good results are obtained by welding cable ends by complete fusion in suitable molds. By this process, good joints may be obtained between copper and aluminum cables. When joining such unlike metals the melted metal should solidify rapidly enough so as to avoid the formation of too large an amount of the brittle Al-Cu alloy.

FEDERICO GIOLITTI
Consulting Metallurgist

"Arc-Torch" for Welding and Heating

MINNEAPOLIS, *Minn.* — In the last few years welding has revolutionized manufacturing processes in plants fabricating both steels and non-ferrous metals. Corresponding improvement in welding equipment and technique has been brought about by close cooperation between scientist and industrialist. Universal use of electrodes, covered or shielded with organic and inorganic materials, produces welds of superior physical properties, and the ready adaptability of semi-automatic mass production mechanisms has enabled the electric arc to all but displace the oxy-acetylene torch in the welding of steel.

However, the gas flame is still widely used for the welding of sheet steel, aluminum alloys, white metal, copper and non-ferrous alloys, for brazing, hard surfacing, surface cleaning and hardening, soldering and many other special applications of localized heat. It should be of interest to note that a new device, the "Arc-Torch", developed by a Minneapolis manufacturer of welding equipment, is quite able to perform many if not all of these operations. It is an attachment for electric welders, and consists of an arrangement of twin carbons of special composition that produce a soft, hot flame when contacted. Referring to the accompanying illustration, the arc is established by pushing the adjusting thumb wheel forward until the inclined carbons, held in clamps, touch and then releasing the forward pressure. The arc is immediately established, and any small adjustment is readily made by turning the thumb wheel. The Arc-Torch is most successfully operated with an a.c. welding machine because of the even arc produced. With d.c. operation, approximately 66% of the total heat is produced at the positive electrode, and a larger carbon must be used at this terminal. The amount of heat is controlled by the amperage. Cost of operation (electrode and current) will be from 15 to 50¢ per hr.

The engraving shows how a short section of copper tubing may be soldered to galvanized steel. The soft, carbonaceous flame is ideal for the application of any of the hard or silver solders on brass, copper, bronze, or nickel-bearing alloys. Soft soldering may be done on copper, brass, galvanized or tinned surfaces, using small carbons and low heats. With special solders, pewter, white metal, and aluminum cooking utensils are readily repaired.

More important applications are to the brazing or soldering of galvanized sheets, even as thin as 30 gage, without destroying the coating provided a brazing flux is used. Important

Arc-Torch Radiates Heat to the Job From an Arc Struck Between Two Inclined Carbons, and Is Able to Do Many Jobs Unadaptable for More Conventional Electric Arc Welding

fabrications of aluminum have been made with the Arc-Torch. The brazing of sheet steel with an alloy-coated rod of silicon bronze has been especially successful, both in repair and new construction. Of even more interest, possibly, is the welding or brazing of cast iron with perfectly sound, dense welds, free from gas pockets and blowholes. This is due to the absence of "blow" or agitation of the molten metal by gas pressure. The use of a newly developed, alloy-coated cast iron rod with Arc-Torch and its carbonizing flame produces welds that are easily machinable, and have color and texture of the parent metal.

Frank W. Scott
Instructor of Metallurgy
University of Minnesota

Rapid Dephosphorization of Rimmed Soft Steels

PARIS, *France* — In Metal Progress for February 1933 (page 49) and again in February 1934 (page 40) we described the principle underlying the Ugine-Perrin process which, by means of the emulsifying action and the mechanical stirring effect of special slags, purifies steels with great rapidity and in such a way as to remove almost the entire phosphorus and oxygen content.

For rimmed steels (steels that are not completely deoxidized) there is a rapid refining method which employs a gaseous stirring. This method, though little known, is used nevertheless on a considerable scale. It is able to convert a rimming soft steel from the basic bessemer converter into a product practically equivalent to an openhearth steel of the same type, particularly with reference to its cold working and deep drawing properties.

We know that rimmed soft Thomas steels containing less than 0.10% carbon usually have a higher tensile strength and lower elongation than openhearth steels of similar analysis. When determined on the standard French tensile test piece (13.8 mm. or 0.543 in. diameter and 100 mm. or 3.94 in. between marks) the elongation for Thomas steel runs only about 26 to 30% instead of 32 to 34% for openhearth steel. The difference is not great, yet it has a considerable effect on deep drawing properties, for instance.

Under normal conditions in Europe, Thomas steel costs considerably less than openhearth steel, so an attempt was made to determine whether it could be improved by some supplementary treatment without destroying the price differential. From the chemical point of view, basic bessemer or Thomas steel contains more phosphorus than openhearth, and this factor was the one to which efforts were primarily directed. The first trials were with duplexing with openhearth or electric furnaces.

The general characteristics of these two methods are as follows:

If Thomas steel is duplexed in the openhearth, the base metal must be only partially overblown in the converter, thus leaving a good part of the chemical reactions for the openhearth. These reactions occur slowly, requiring several hours, during which the melt acquires the properties of openhearth steel. This requires a large installation as to number and capacity of openhearth furnaces and consequently a considerable capital investment. However, under normal conditions in Europe there is only a very slight difference between the final cost of this duplex steel and of openhearth steel.

At present the Thomas-electric duplex process may be considered only as a more rapid method of doing the same thing that an openhearth furnace can do. Because of the high operating cost of an electric furnace it does not provide an economical method. Since dephosphorization of the Thomas steel must be stressed, it is necessary to make two slags in the electric furnace, an oxidizing slag for dephosphorization followed by a deoxidizing slag to bring the steel down to the desired rimming action in the ingot molds.

In attempting to simplify this operation in the electric furnace, Robert Lemoine devised the following process:

Thomas steel from the converter, being already strongly oxidized, is partially dephosphorized by bringing it into close contact, in the ladle used to convey it to the electric furnace, with vigorous bases or alkalis.

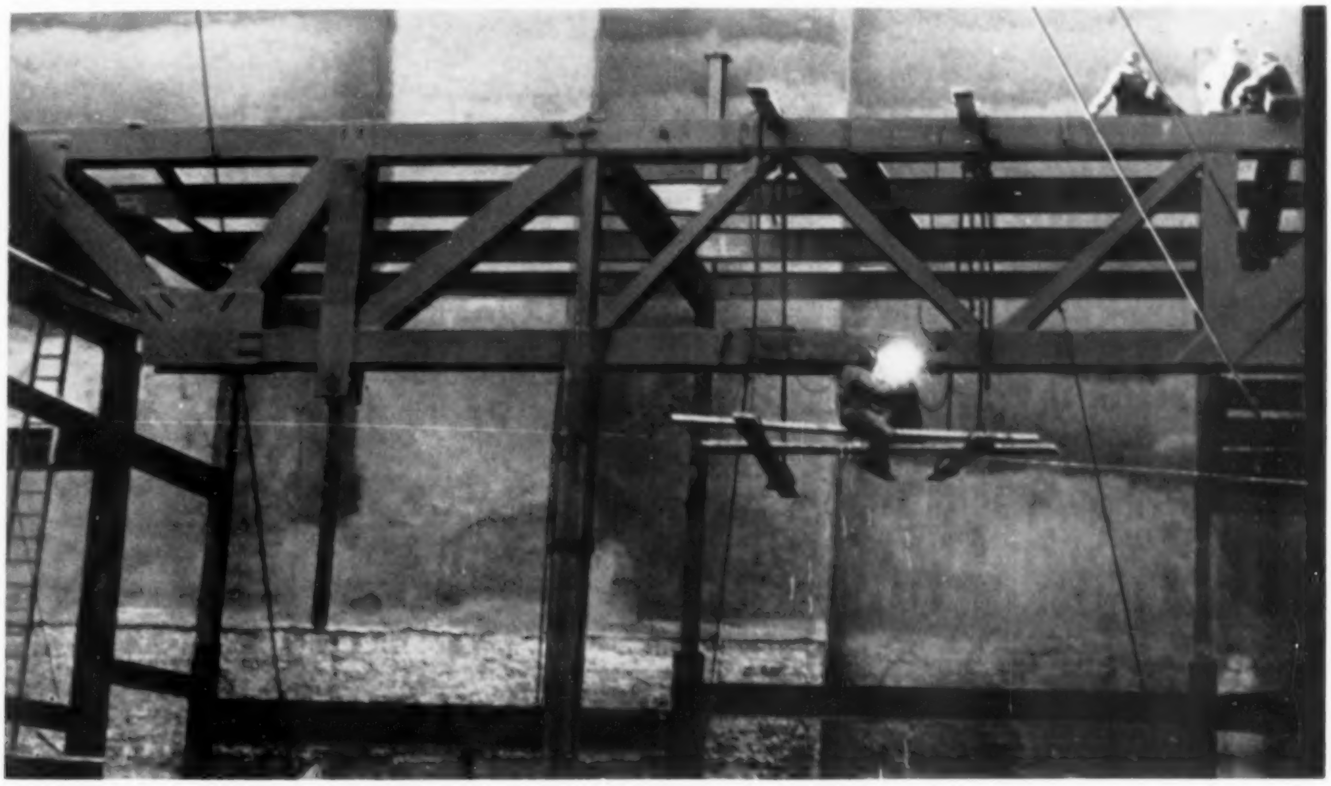
Sodium carbonate, the most common alkaline base, could not be used alone because it dissociates at the high temperature and on contact with liquid steel. It may, however, be stabilized by the addition of other products such as alumina or titanium oxide. These additions even transformed it into a product whose decomposition and gas formation when in contact with the steel could be regulated; this in turn regulates the stirring action in the ladle.

(Continued on page 688)

Important Structures Welded

NEW YORK, *N. Y.* — Everyone knows that welding is becoming more and more important, but few realize the speed at which this advance is occurring. This may be measured by figures from the American Iron and Steel Institute showing that 183,436,000 lb. of steel welding wire was produced in 1939, an increase of 56% over 1938. The relative figure is sufficiently imposing; the tonnage itself is large, representing the total output from one 100-ton openhearth furnace for the entire year.

In the field of structural engineering the advances are correspondingly rapid. From many examples may be selected the 22-story nurses' home for Medical Center, N. J., containing 2200 tons of structural steel, and probably the largest building yet to be completely field welded. Approximately 18,000 ft. of ¼-in. equivalent bead were necessary; part of the wind bracing connections required ⅞-in. butt welds. Tier building welding has become so common that the American Institute of Steel Construction has promulgated recommended practices for welded connections.



Welding the Splice in the Bottom Chord of a 30-Ton, 70-Ft. Truss That Carries a Five-Story Office Building Above the Auditorium of a Newsreel Theater. Post under second panel point is a temporary support during erection. Photo courtesy Wilson Welder and Metals Co.

An interesting account of the development of welded industrial buildings was recently given by ALBERT S. LOW, chief engineer of The Austin Co., to a large group of engineers in Washington. He cited among many others the structure erected for Electro-Motive Corp.'s diesel locomotive works at LaGrange, Ill. He said in this address:

"When we first broached the subject of welding to the executives of Electro-Motive, they expressed their misgivings. They listened to all of our arguments but still maintained their preference for conventional riveted construction. Then one day we learned that instead of using castings for the locomotive frames of their streamlined diesel giants, they were going to weld them. We confronted the management with the apparent inconsistency of their position. How could they insist upon riveted construction when they were going to weld the most critical parts of their product? As this point they explained that they had problems of their own in trying to convince the railroad executives that welded frames were every bit as safe as cast frames.

"Now, whenever anyone questions the use of welded locomotive frames, they just usher him into the shop, point up to the 200-ton traveling

crane and remind him that welded connections are all that hold the building up. Nobody has ever run out from fright."

That architects, engineers, owners, and building codes in important cities are willing to depend on important welded connections is again proven (if proof be again needed) by the construction of a building to the writer's designs for an air-travel terminal, located on the site of the old Belmont Hotel across 42nd street from Grand Central in New York City. This building is unique in many aspects besides being devoted primarily to the convenience of airplane travellers. On the street level will be a number of stores and in addition a newsreel theater, and in order to provide for these varied facilities, it has been necessary to employ many unusual structural designs.

Perhaps the most interesting elements of this project are the large all-welded steel trusses and the deep all-welded plate girders. The trusses are designed for a span of 70 ft. and weigh 30 tons apiece. Top and bottom chord members are 14-in. rolled H-sections. The end reaction of one truss amounts to 800,000 lb. and the stress in the tension chord member at the field splice is 1,800,000 lb. Slot as well as fillet welds were necessary at the principal intersections. These trusses frame into short heavy plate girders (also welded) with a depth exceeding 6 ft.; it was necessary to resort to these heavy trusses inasmuch as columns could not be permitted in either the theater or the Terminal floors. The trusses are to support the five floors of offices above.

Gilbert D. Fish
Consulting Engineer

If

You Want to Be an Openhearth Man

Editor's Note — A mutual friend of Al. Adams, assistant superintendent of openhearths and foundry at Homestead Steel Works, and Max. W. Lightner, author of the discussion of openhearth methods on page 647, sends us the following rhyming quatrains from Al's muse, noting that it will mean a lot to the modern steel maker, even if he doesn't have to "burn up the stacks" on Sunday to prevent the byproduct ovens from overburdening the air with SO_2, or even have to waste 50 heats of lining life on high temperature for a heat of "Metalloid — High Chrome".

If—You Want to Be an Openhearth Man

If you can take your off-grade iron, and junk, and tin scrap
And make your heat, and pour it clean — no seams —
And calmly listen while they search for reasons
Why a modern mill can't roll it into beams;

If you can use your every wile and effort
And save a shady heat from going t'ell
And still not run amuck when you're confronted
With "7 sloppy, ragged stream", and "50 lb. of skull";

If you can strive, and sweat, and swear for six days
To get three million B.t.u.'s per ton — and win! —
And watch them burn your stacks up on the seventh,
To waste the gas you saved, and still not sin;

If you can turn out heats that swell your ego
(You've squeezed that last thin drop from warp and weal)
And still sit back and smile with calm complacence
At "15,000 lb. of slivers; rotten steel";

If you can make them 15 heats of seamless,
And mix in other specials, and not blow
A single heat for "off-grade", "sloppies", "rejects",
And take your "hell" because a couple melted low;

If you can squeeze the last lame ton from roof brick,
And then be called upon for "Metalloid — High Chrome —"
And have to burn off 50 heats of life to make it
And still not talk too raw, nor even moan;

If you can spend 600 man-hours cleaning
For visitors they say will surely come
And not go berserk when they call you
And say they won't be here, they've all gone home;

If you can use your soundest judgment,
And take the course you know will cost the least
And get your ears knocked down and bloodied
And still be loyal, and not stoop to cries of "Beast";

If you can fill each 15-hour work day
With 18 hours worth of tonnage run,
You're an O. H. Man, My Son — God Bless You!
And You'll Get Your Praise in Heav'n or Hell — By Gum!

Al. Adams

Toolsteels Classified by Wear-Toughness Ratio

By Harold B. Chambers

Each of the three groups arranged in order of increasing toughness (estimated average value). Figures indicated as maximum are optional and may be present up to amount specified. Since the difference in relative wear-toughness capacities of adjacent classes is small to negligible, the many brands covered by each class may be expected to give competitive performance except when highly standardized operating conditions require that consideration be given to the footnotes.

Class	Conventional Type Names	Carbon	Manganese	Silicon	Tungsten	Chromium	Vanadium	Molybdenum	Cobalt	Nickel	Notes
	Water Hardening Steels										
1A	Tungsten finishing	1.25-1.50	0.15-0.35	0.15-0.50	2.50- 6.00	1.80 max.	0.30 max.	0.50 max.			A,B,C
1B	Carbon or carbon-vanadium	1.30-1.45	0.15-0.35	0.15-0.35		0.35 max.	0.30 max.				A,C
2A	High carbon, low tungsten	1.10-1.30	0.15-0.35	0.15-0.35	1.00- 2.50	0.35 max.	0.30 max.				A,B
2B	Low chromium or chrome-vanadium	1.10-1.30	0.15-0.35	0.15-0.35		0.10- 1.20	0.30 max.				A,C
2C	Carbon or carbon-vanadium	1.10-1.30	0.15-0.35	0.15-0.35			0.30 max.				A
3A	High carbon, low tungsten	0.90-1.10	0.15-0.35	0.15-0.35	1.00- 2.50	0.75 max.	0.30 max.				A,B,C
3B	Low chromium or chrome-vanadium	0.90-1.10	0.15-0.35	0.15-0.35		0.10- 1.50	0.30 max.				A,C
3C	Carbon or carbon-vanadium	0.90-1.10	0.15-0.35	0.15-0.50			0.50 max.				A,D
4A	Chrome-molybdenum or chrome-vanadium	0.55-0.90	0.15-0.35	0.15-0.35		0.40- 1.20	0.35 max.	0.25 max.		0.50 max.	A,C
4B	Carbon or carbon-vanadium	0.70-0.90	0.15-0.35	0.15-0.35			0.30 max.				A
4C	Silico-manganese or silico-molybdenum	0.45-0.75	0.35-1.00	0.75-2.25		0.60 max.	0.35 max.	0.60 max.			A,E
	Oil Hardening and Air Hardening Steels										
5A	High carbon, high chromium	1.80-2.50	0.15-1.20	0.15-1.00	2.00 max.	10.50-14.00	1.25 max.	0.30 max.	1.00 max.	1.00 max.	A,F,G
5B	High carbon, high chromium	1.80-2.40	0.15-0.60	0.15-0.50		10.50-14.00	1.20 max.	0.70- 1.00	0.60 max.		A,F,G
5C	High carbon, high chromium	1.30-1.70	0.15-0.60	0.15-0.50		10.50-14.00	1.20 max.	0.50- 1.25	4.00 max.	1.00 max.	A,F,G
5D	High carbon, high chromium	0.90-1.30	0.15-1.20	0.15-1.00		4.50-13.00	0.75 max.	0.70- 1.25	0.60 max.		A,F,G
6A	Chrome-molybdenum	1.10-1.30	0.35-0.95	0.15-0.35		0.40- 1.75		0.25- 0.75			A,E
6B	High carbon, low tungsten	1.10-1.30	0.15-0.70	0.15-0.35	1.00- 2.50	0.35- 1.25	0.30 max.				A,B,C
6C	Low chromium or chrome-vanadium	1.10-1.30	0.35-0.70	0.15-0.35		0.40- 1.50	0.30 max.				A,C
7A	Chromium non-deforming	0.90-1.10	0.35-1.10	0.15-0.50	1.10 max.	0.90- 1.60	0.30 max.	0.50 max.			A,E
7B	Manganese non-deforming	0.80-1.10	0.85-1.80	0.15-0.50	0.70 max.	0.90 max.	0.30 max.	0.35 max.			A,E
8A	Low tungsten-chromium	0.40-0.65	0.15-0.35	0.15-1.50	0.75- 3.00	0.50- 2.00	0.50 max.	0.35 max.			A,E
8B	Chrome-nickel or chrome-nickel-molybdenum	0.50-0.80	0.35-0.90	0.15-0.35		0.50- 1.25	0.30 max.	0.80 max.		1.00-2.50	A,E
8C	Chrome-molybdenum, chrome-vanadium, or manganese-molybdenum	0.50-0.90	0.35-0.90	0.15-0.50		1.20 max.	0.35 max.	0.40 max.		0.50 max.	A,E
8D	Silico-molybdenum	0.45-0.60	0.35-1.25	0.75-2.25	0.20 max.	0.75 max.	0.60 max.	0.15- 2.00			A,E
	High Speed (H.S.) Steels and Hot Work (H.W.) Steels										
9A	Tungsten-cobalt high speed	0.70-0.90	0.15-0.35	0.15-0.35	18.00-23.00	3.50- 4.75	1.25-2.50	1.25 max.	9.00-15.00		A,G,H
9B	Tungsten-cobalt high speed	0.65-0.90	0.15-0.35	0.15-0.35	17.00-21.00	3.50- 4.75	1.25-2.50	1.25 max.	5.00- 9.00		A,G,H
9C	Molybdenum-cobalt H.S.	0.75-0.90	0.15-0.35	0.15-0.35	2.00 max.	3.50- 4.75	1.25-2.50	7.00-10.00	3.00- 8.00		A,G,H
9D	Tungsten-cobalt high speed	0.65-0.80	0.15-0.35	0.15-0.35	17.00-20.00	3.50- 4.75	0.75-1.50	1.00 max.	2.00- 5.00		A,G,H
9E	Tungsten-cobalt high speed	0.65-0.85	0.15-0.35	0.15-0.35	12.00-15.00	3.50- 4.75	1.50-2.25	0.75 max.	3.00- 8.00		A,G,H
10A	18-4-4 and 18-4-3 high speed	0.90-1.30	0.15-0.35	0.15-0.50	17.00-19.00	3.50- 4.75	2.50-4.00	1.00 max.			A,H
10B	18-4-2 high speed	0.75-0.90	0.15-0.35	0.15-0.50	17.00-19.00	3.50- 4.75	1.50-2.50	1.00 max.			A,H
10C	18-4-1 high speed	0.55-0.80	0.15-0.35	0.15-0.75	16.00-21.00	3.50- 4.75	0.50-1.50				A,H
10D	Molybdenum-tungsten H.S.*	0.70-1.30	0.15-0.35	0.15-0.35	5.00- 6.50	3.50- 4.75	1.25-4.00	4.00- 6.50			A,H
10E	Molybdenum-vanadium H.S.*	0.70-1.30	0.15-0.35	0.15-0.35		3.50- 4.75	1.50-4.00	7.00- 9.00			A,H
10F	Molybdenum-tungsten H.S.	0.65-0.85	0.15-0.35	0.15-0.35	1.00- 2.50	3.50- 4.75	0.75-1.50	6.00- 9.50			A,H
10G	14-4-2 and 14-4-1 high speed	0.55-0.80	0.15-0.35	0.15-0.35	13.00-15.00	3.50- 4.75	0.75-2.25				A,H
11A	Low carbon high speed	0.45-0.60	0.15-0.35	0.15-0.35	16.00-19.00	3.00- 4.50	0.50-1.25				A,H,I
11B	High tungsten hot work	0.25-0.60	0.15-0.35	0.15-0.35	12.00-16.00	2.50- 4.50	0.30-0.60				A,H,I
11C	Tungsten hot work	0.25-0.50	0.15-0.35	0.15-0.35	8.00-12.00	1.25- 3.50	0.60 max.	0.30 max.		2.25 max.	A,H,I
11D	Tungsten-chromium H.W.	0.30-0.60	0.15-0.75	0.35-1.50	4.00- 7.50	4.50- 7.50	0.60 max.	0.50 max.	0.60 max.	0.50 max.	A,H,I
12A	Low tungsten-chromium H.W.	0.40-0.65	0.15-0.35	0.15-1.00	1.50- 3.00	0.75- 2.00	0.50 max.	0.35 max.			A,H
12B	Chrome-molybdenum H.W.	0.30-0.50	0.15-1.25	0.80-1.10	1.25 max.	4.00- 7.50	0.50 max.	0.45- 1.75	0.60 max.	1.75 max.	A,H
12C	Chrome-molybdenum H.W. or chromium hot work	0.40-1.00	0.15-0.75	0.15-0.75		2.25- 4.50	1.00 max.	0.80 max.			A,H
12D	Chrome-nickel hot work or chrome-nickel-molybdenum hot work	0.30-0.60	0.35-0.80	0.15-0.35		0.50- 2.50	0.30 max.	1.00 max.		1.25-5.00	A,H

A. Wear resistance increases and toughness decreases as carbon content increases.

B. Wear resistance increases and toughness decreases as tungsten content increases.

C. Hardenability increases, wear resistance increases, toughness decreases, movement in hardening decreases, and tendency for soft spots in hardening decreases as chromium content increases.

D. Some special applications (silverware striking dies, certain header dies, etc.) may occasionally require extra penetration of hardness, which may be produced by adjusting manganese and silicon contents.

E. Hardenability increases, wear resistance increases and toughness decreases as total alloy content increases.

F. Machining difficulties increase as total alloy content increases.

G. Red hardness properties increase and toughness decreases as cobalt content increases.

H. Red hardness properties increase and toughness decreases as total alloy content increases.

I. Water cooling surface in operation, particularly when intermittent, tends to promote heat checking approximately in proportion to tungsten content.

*Relative position based on lower carbon ranges only.

By Harold B. Chambers
Metallurgist
Atlas Steels Limited
Welland, Canada

Choice of Toolsteels According to Their Wear-Toughness

EVEN THOUGH the use of toolsteels permeates all industry, and much scientific, technical and practical information on toolsteels is available, the average consumer still approaches the problems of choosing a new steel for a troublesome job or an old reliable one for a new application with a considerable degree of uncertainty. Whatever may be the reason for this attitude, it results that he depends to a considerable degree upon the recommendation of the steel maker.

When the steel supplier is consulted it is a usual procedure for a well-qualified representative or service metallurgist to visit the consumer's plant to diagnose the problem at hand. It is necessary for this man to have all the information available about the operating conditions. A physician cannot prescribe for his patient without an examination and so it is with the toolsteel manufacturer. Toolsteels are being machined into innumerable shapes, hardened under the most variable conditions, used for fabricating materials of variable hardness and toughness, in all sizes of machines operating at different speeds, and of different types and states of repair. Consequently, the steel representative must not only have a knowledge of the relative working properties of his toolsteels but he must also possess a mechanical sense in order to evaluate the service requirements. This so-called mechanical sense has been developed inherently by the average toolsteel consumer because of his very background and if he could be given a basic conception of the whole toolsteel system he should have an improved understanding of the application of toolsteels. It will be my endeavor to approach this very vital industrial problem from the standpoint of chemical composition.

Basic is the conception that *all* steels of *all* types are fundamentally alloys of iron and carbon.

During the melting of the iron base it acquires oxygen, which must be counteracted to produce good quality steel. The addition of about 0.25% silicon offers the most convenient way of obtaining the desired effect. However, this simple steel cannot be safely forged or rolled, and in order to improve the hot workability it has been found advantageous to add about 0.25% manganese. Phosphorus and sulphur are also present but they are always reduced to inconsequential proportions, usually under 0.030%, and may therefore be disregarded. Hence, using commercial ranges, the chemical basis for toolsteels becomes iron plus carbon plus 0.15 to 0.35% manganese plus 0.15 to 0.35% silicon. If the steel contains appreciably greater percentages of silicon and manganese than 0.35, the additional amount functions as an "alloy", that is, has been added to enhance the physical properties.

Now, by varying the carbon content in this simple steel the various plain carbon steel "tempers" are produced. Such carbon steel tools have been used since time immemorial, and experience has demonstrated that for the widely diversified tool applications the carbon content should not be less than about 0.70% or more than 1.50% for best results. It has also been learned from experience that as the carbon con-

tent is increased the resistance to wear increases at the expense of toughness. To gain an idea of the wear-toughness capacity of each "temper" (or carbon range of 0.10%) refer to the table on this page.

The mechanically trained mind should grasp from the list of typical applications a good idea of the limitations of each temper as determined by the test of time. He will also realize that there is an association between the tempers which reveals four distinct fields of application, namely 1.30 to 1.50% for wear tools, 1.10 to 1.30% for cutting tools, 0.90 to 1.10% for dies and 0.70 to 0.90% carbon for shock tools. In other words, experience has demonstrated that the wear-toughness ratio of plain carbon toolsteels does not vary appreciably for a 0.20% carbon range.

It is necessary to resort to microscopic examination of fully hardened specimens to disclose the cause of increased wear resistance with higher carbon content. Such examination reveals that hard iron carbide spheroids become more plentiful as the carbon increases but otherwise the structure remains unchanged. These spheroids of carbide begin to appear in the microstructure when the carbon passes about 0.85%, the "eutectoid" composition. The surface hardness attainable in a higher carbon or hyper-eutectoid steel is no greater than that obtainable with eutectoid carbon toolsteel. By proper heat treatment, for example, it is possible to make an 0.85% carbon steel equal in hardness to a 1.40% carbon steel, but the wear resistance will be much less. Perhaps too frequently *hardness* of toolsteel is taken as a measure of wear resistance and the amount of excess carbide in the structure is overlooked. In passing it may be said that one of the effects of adding alloys to toolsteels is to lower the eutectoid carbon content and thus increase the excess carbide for a specific carbon content.

Application and Evaluation of Plain Carbon Toolsteels

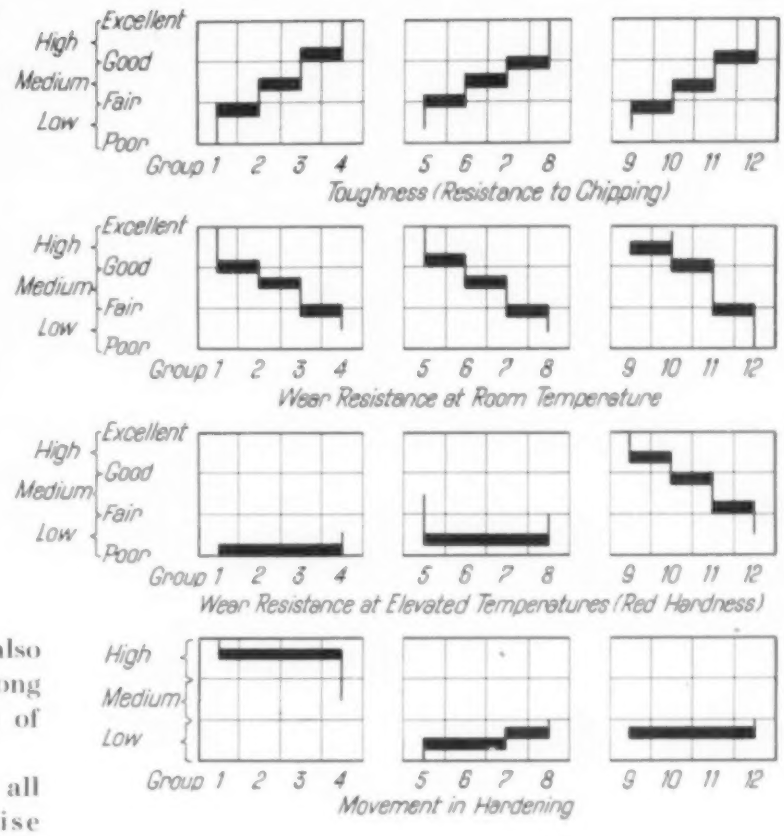
Temper	Typical Applications	Relative Evaluation	Wear-Toughness Rating
1.40 to 1.50% C 1.30 to 1.40% C	Engravers' tools, wire drawing dies Files, lathe tools	Resistance to wear paramount Toughness slightly important	Excellent wear resistance Poor toughness
1.20 to 1.30% C 1.10 to 1.20% C	Twist drills, stone planers Taps, threading dies	Resistance to wear very important Toughness important	Good wear resistance Fair toughness
1.00 to 1.10% C 0.90 to 1.00% C	Blanking and forming dies Header dies, shear blades	Resistance to wear important Toughness very important	Fair wear resistance Good toughness
0.80 to 0.90% C 0.70 to 0.80% C	Rivet sets, pneumatic chisels Hammers, wedges	Resistance to wear slightly important Toughness paramount	Poor wear resistance Excellent toughness

Carbon toolsteels were those originally available to the toolmaker and a good many years ago it became apparent that they were not keeping abreast of industry's demand. The steel maker not only had to think about improving the toughness or wear resistance of the carbon steels, as the case might have been, but being water hardening steels, he found they were not very suitable for dies or tools of intricate design or those that could not be ground after hardening, because of the pronounced tendency of water hardening steels to warp, crack, and change size. He also was called upon to improve the resistance to heat of the available steels in order to cope with high operating temperatures that began to be developed by heavier machining methods and more intricate hot forging jobs. From the consumer's point of view it appeared that toolsteel manufacturers had to expand their product into a system such as shown in the table at the foot of the next page.

Based on the idea that modern metallurgists have been able to develop toolsteels for each of the above 12 groups, a survey of the toolsteels being offered in the United States and Canada was made by first allocating them into their primary fields of application and then estimating in a relative manner their more essential properties at the respective working hardness ranges by consulting appropriate literature, fundamental metallurgy, local laboratory work, and personal service experience.

When reference is made to the toughness and wear resistance of toolsteels the user should not visualize these properties in the same sense as he views standard impact and hardness tests. Robert S. Rose presented an illuminating discussion of the concept of toughness in Metal Progress for April (page 407). Hardness and wear resistance have only a general relationship in the lower ranges, and as mentioned earlier

ppraisal of Properties of Toolsteels Commer-al in U. S. and Canada Indicate Character-tic Properties for Each Group, Although There Seldom Is a Clear-Cut Demarcation



in this article, superior wear resistance is associated with excess carbides, and these have little or no influence on the standard Brinell and Rockwell hardness tests.

In shop practice, "toughness" is most often manifested and evaluated as resistance to chipping (or less frequently in its relative forms of breakage and crumbling), which obviously may not be considered a true impact property in very many, if any, applications. Tensile or compressive properties and fatigue resistance may also enter into the problem of chipping along with the actual hardness and structure of the steel.

Generally speaking, practically all applications represent a compromise between so-called toughness and wear resistance; when a tool chips, breaks, or crumbles under a given set of service conditions from any combination of fundamental causes, we must usually make the steel less wear resistant either by tempering it softer or resorting to a type of steel which is inherently less wear resistant. The wear resistance in such an appraisal must be estimated on "life per grind" in order to avoid the fact that many of the water hardening steels start to become relatively shallow hardening in sections over about ½ in. and naturally would not permit as many regrindings as the deeper hardening steels.

The first diagram contains the result of this survey and indicates that each group has a range of combinations of toughness, wear resistance, and movement in hardening. The broad, solid, horizontal portions of the steps have been made to convey the fact that there is no clear-cut line of demarcation between groups but rather a blending, each into the adjacent ones.

We have learned that toughness is sacrificed more or less in proportion to a given increase in wear resistance. It is only natural that we would like all the wear resistance obtainable, if only for the sake of economy, but the toughness required necessarily limits this property. Consequently, in evaluating the service conditions, our thoughts may be largely confined to the toughness only. If the application is such that no appreciable shock is encountered then the steels with highest wear resistance can be selected if production warrants, but if considerable shock must be met then wear resistance must be largely sacrificed in the interest of toughness regardless of production demands. What has been so far developed can be summed up in a convenient diagram such as the target shown on the next page, or in any other geometric form that suits the individual's taste.

However, unless the toolsteel consumer could identify his steels according to the present theoretical classification, its practical adaptation would be very limited. As an attempt to find a simplified identification, a composite chemical analy-

Primary Field of Application	Primary Steel Requirement		
	Movement in Hardening Unimportant	Movement in Hardening Important	Resistance to High Temperatures Important
Maximum wear resistance	Group 1	Group 5	Group 9
General cutting tools	Group 2	Group 6	Group 10
General die work	Group 3	Group 7	Group 11
Maximum toughness	Group 4	Group 8	Group 12

sis of the steels falling into each group was made. It is realized that new analyses are continually being tried, that it is impossible to know in all cases the exact chemical ranges to which the various steels are being made, and that it would be extremely unlikely all steels have been detected. However, it is believed that all the steels that have been given the test of time, or surely all the more popular grades in the United States and Canada at the present time, have been included. This compilation is shown in the table on the next page, wherein alloys that are common to all steels in a given group have been printed in italic figures. (Manganese and silicon have not been italicized unless they are above the necessary 0.15 to 0.35% in all grades.)

While these broad analyses give us a clue to the steels covered by most of the groups there is too much overlapping for it to be very useful for purposes of identification, and a hopeless feeling in regard to making a classification based on chemical analysis may be gained.

Fortunately, however, the designing of steels is not simply based on indiscriminately adding so much of this or that alloy to get an endless number of combinations. Instead, the hardenability (ability to develop full hardness below the surface with an increase of section) must be controlled within reason, for given fields of application, by "balancing" the alloy content. So much of *this* alloy is approximately equivalent to so much of *that* alloy, and so on. This fact makes it possible to take the specification analyses of the many toolsteel brands and combine them into empirical class analyses as shown in the data sheet, page 663.

It is believed that these class analyses will identify practically all toolsteels into their respective groups. Furthermore, it is also believed that the many brands covered by each class analysis — when given their own suitable heat treatments — will give competitive performances over a period of time under a majority of operating conditions. In other words, the difference between success and failure should not be expected by choosing brands covered by a given class analysis except when conditions indicated by the footnotes must be considered. Consideration of these footnotes may be necessary when operating and manufacturing conditions are highly standardized.

With this present conception of the interrelationship of toolsteels, a steel is first placed into its proper group and secondly into its relative position within the group. The class position is based on the estimated average properties, which implies that the classes overlap. In other words, for some applications the higher carbon, higher alloyed combinations of one class may be equivalent in performance to the lower carbon, higher alloyed combinations in the adjacent class (or the higher carbon, lower alloyed combinations).

In some applications, experience should indicate that any one of the classes in a given group will give satisfactory performance. It would be ideal if types in each group could be designed so that by variation in heat treatment they would cover their entire field of application with equally good results and blend into the contiguous groups, thus forming a toolsteel Utopia of 12 steels (or a lesser number, if a

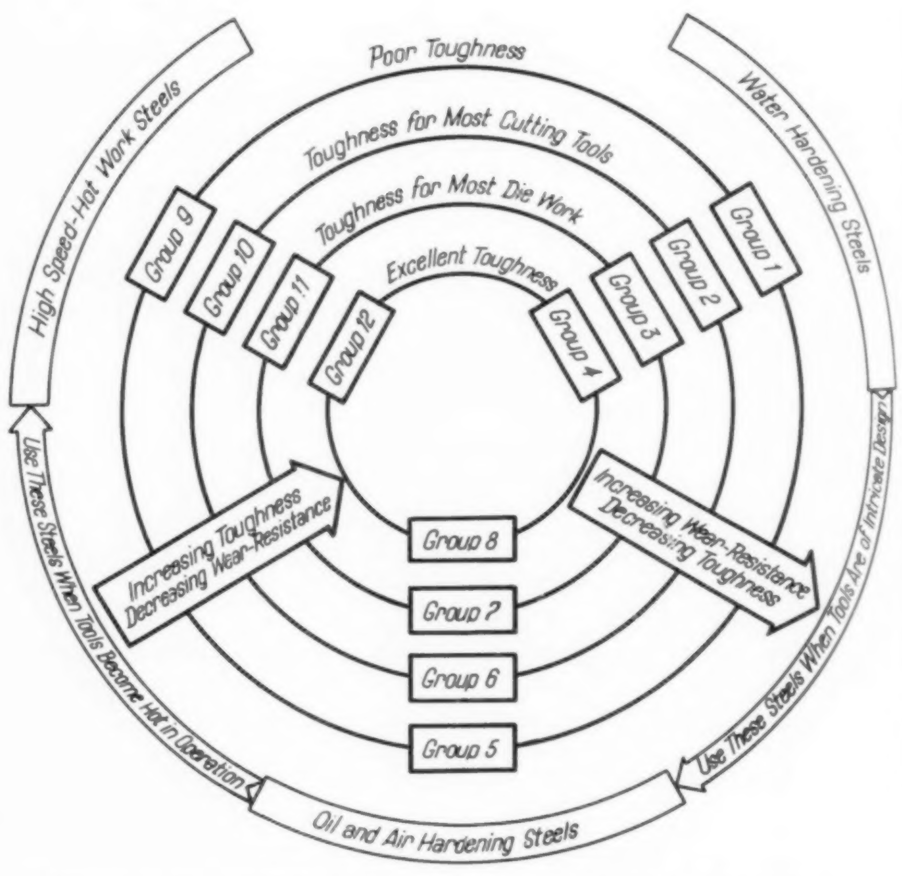


Diagram to Indicate Changes in Type of Toolsteel to Be Chosen When in Trouble or When Selecting a Steel for a New Tool or Application

Composite Chemical Analysis of Steels in Each Group

Group	Carbon	Manganese	Silicon	Chromium	Tungsten	Vanadium	Molybdenum	Cobalt	Nickel
1	*1.25–1.50*	0.15–0.35	0.15–0.50	0.0 – 1.80	0.0– 6.0	0.0 –0.30	0.0– 0.50	....	....
2	*1.10–1.30*	0.15–0.35	0.15–0.35	0.0 – 1.20	0.0– 2.50	0.0 –0.30	....	....	....
3	*0.90–1.10*	0.15–0.35	0.15–0.50	0.0 – 1.50	0.0– 2.50	0.0 –0.50	....	....	....
4	*0.45–0.90*	0.15–1.00	0.15–2.25	0.0 – 1.20	....	0.0 –0.35	0.0– 0.60	....	0.0–0.50
5	*0.90–2.50*	0.15–1.20	0.15–1.00	*4.5 –14.00*	0.0– 2.00	0.0 –1.25	0.0– 1.25	0.0– 4.00	0.0–1.00
6	*1.10–1.30*	0.15–0.95	0.15–0.35	*0.35– 1.75*	0.0– 2.50	0.0 –0.30	0.0– 0.75	....	....
7	*0.80–1.10*	*0.35–1.80*	0.15–0.50	0.0 – 1.60	0.0– 1.10	0.0 –0.30	0.0– 0.50	....	....
8	*0.40–0.90*	0.15–1.25	0.15–2.25	0.0 – 2.00	0.0– 3.00	0.0 –0.60	0.0– 2.00	....	0.0–2.50
9	*0.65–0.90*	0.15–0.35	0.15–0.35	*3.5 – 4.75*	0.0–23.00	*0.75–2.50*	0.0–10.00	*2.0–15.0*	....
10	*0.55–1.30*	0.15–0.35	0.15–0.75	*3.5 – 4.75*	0.0–21.00	*0.50–4.00*	0.0– 9.50	....	....
11	*0.25–0.60*	0.15–0.75	0.15–1.50	*1.25– 7.50*	*4.0–19.0*	0.0 –1.25	0.0– 0.50	0.0– 0.60	0.0–2.25
12	*0.30–1.00*	0.15–1.25	0.15–1.10	*0.50– 7.50*	0.0– 3.00	0.0 –1.00	0.0– 1.75	0.0– 0.60	0.0–5.00

single steel could be designed to completely cover more than one field of application). While this Utopian goal may never be attained it has already been approached to a remarkable degree.

A useful basis for initial selection of a steel would be knowledge about the class steel in each group that has been given the widest application. In some groups such classes may be well established, while in others the inference may be made that when a class covers the greatest number of competitive brands in a given group, this popularity denotes the best ability to cope with its particular field of application. However, it is probably the better part of valor to permit the user to make this choice himself!

The controversial nature of this undertaking is well realized and there are, undoubtedly, production figures available to prove or disprove almost any comparison of toolsteels in given services. For this reason individual experiences may not confirm the present physical property evaluation of all the various types of toolsteel. An attempt has been made to approach this subject from the broadest viewpoint, in as practical a manner as possible, so that it may serve the average consumer by giving him a conception of the whole toolsteel system without confusing anomalies.

It is admitted that each brand of toolsteel possibly possesses its own so-called personality and that it may perform remarkably if its soulmate applications are found in industry. However, it is believed that so long as the physical variations attending most applications exist by necessity in individual machines, in their operation, and in the materials being fabricated, as well as in the tools or dies themselves, and until more appropriate methods of evaluating these variable service conditions and the toolsteel working properties are available, we should assume a rather broad, compromising viewpoint. If we are to solve our tool problems without undue delay we should look upon the intrinsic merits or subtleties of one brand over another of the same class and apparent hardening characteristics as minor or even incidental, and not of sufficient magnitude to account for success or failure.

One brand may possess slightly better wear resistance than a competitive brand when heat treated to its respective working hardness range, but as toughness is ordinarily sacrificed for wear resistance a test of time will very frequently show about equivalent performances unless conditions are highly standardized. Ordinarily such ideal set-ups are not available to capitalize on small inherent qualities. The slightly tougher steel will withstand unusual shocks better and thus over a period of time may exhibit just as good an average production, because spalling, chipping, and breakage will be less to offset the better production per grind of the other steel while operation is going along smoothly.

Compromise Viewpoint

Such a compromise viewpoint must not be disregarded. That is the reason emphasis has been placed on the opinion that the end results of competitive brands of the same class, as arranged in this toolsteel conception, will be very similar over a period of time in many applications. Sometimes circumstances of a fortuitous nature are hidden and thus permit competitive brands to solve an otherwise intangible tool problem. In dealing with this subject, it has necessarily been assumed that all allied conditions associated with the performance of toolsteels will be satisfactory or properly explored.

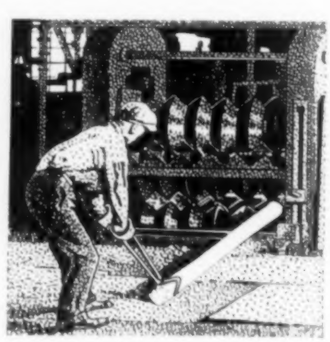
In spite of the great diversity of application, the major troubles encountered in the use of toolsteels may be grouped as follows:

1. Wear out too soon in service.
2. Chip or break in service.
3. Change size in hardening.
4. Distort or crack in hardening.

Obviously, only one phase of toolsteels, their selection, has been treated here and it must be appreciated that any one of these troubles may be associated with the heat treatment as well as the selection of the steel. Hence a proper diagnosis of a given problem cannot be made unless full consideration is accorded both conditions. Much valuable time is lost and needless expense incurred by unsound experimentation when a steel is condemned, which in reality has been wrongly applied or improperly heat treated. Even though the proper steel has been selected it is frequently necessary to work out the proper heat treatment for a given application. Patience in this matter will usually be rewarded with a quicker solution of a problem than when blind jumping from one grade of toolsteel to another is practised at the first suggestion of poor performance.

It may be helpful to illustrate the practical aspect of this theory of toolsteel selection with a group of 10 examples which have been chosen with the idea of showing its flexibility in use:

Example 1 — Lamination die for silicon sheet for electrical transformer work, made from 0.95% C, 1.20% Mn, 0.25% Si, 0.40% W, 0.55% Cr steel, gave uneconomical production. By referring to the class analyses (page 663) we find this is Class 7B. Since a non-deforming steel is required we must stay with the oil or air hardening steels and since toughness is of no serious consideration in such work we can select a steel in Group 5, the one with highest wear resistance.



Example 2 — Machine punches for cold punching ¼-in. holes in ¼-in. strips were made from 0.53% C, 0.30% Mn, 0.45% Si, 2.25% W, 1.40% Cr, 0.25% V steel and gave abnormal breakage. By referring to class analyses, we find this is Class 8A, which is the right location for a job of this kind. Punching the hole of the same diameter as the thickness of the stock is a difficult job under any circumstance, and simply means the punch must possess maximum toughness especially when of small cross-section. The toughest steels in this group are Class 8D, which is the one to use. The footnote states that the more alloy Class 8D steels contain the less tough they become, so that a grade with a minimum amount of alloy should be considered.

Example 3 — Cold drawing die made from a 1.38% C, 0.30% Mn, 0.25% Si, 4.10% W, 1.12% Cr steel would not shrink sufficiently in re-hardening. By referring to class analyses, we find this is Class 1A which is the proper type for such work, as maximum wear resistance is required and toughness is of no consideration. The footnote states chromium reduces movement in hardening, so a grade should be selected with a minimum of this element.

Example 4 — Punch die with sharp cornered square holes made from 1.04% C, 0.25% Mn, 0.20% Si, 0.39% Cr cracked in water quench. Referring to class analyses we find this is Class 3B. Since distortion is not a problem it is not necessary to shift to the Group 7 non-deforming steels of the same wear resistance capacity. The footnote states that chromium increases hardenability and as increased hardenability promotes quenching strains in a water hardening steel we can correct our trouble by selecting a Class 3C steel in this same group.

Example 5 — Extrusion dies for automobile valves made from 0.38% C, 0.30% Mn, 0.21% Si, 11.22% W, 2.87% Cr, 0.47% V steel washed out quickly in operation. Referring to class analyses we find it is Class 11C. The footnote states that increasing the alloy content increases the resistance to heat or red hardness. Since we already are using a steel near the top side of its class it is apparent that to gain an appreciable improvement, which we obviously need, we should go to a considerably higher alloyed type in this group, compatible with sufficient toughness.

Example 6 — High speed tools for turning alloy cluster gear forgings in high speed, heavy duty automatic machines were made from a 0.73% C, 0.22% Mn, 0.33% Si, 17.92% W, 3.97% Cr, 1.14% V steel but gave low production. We find this is Class 10C and as the tools are well supported, thus reducing shock to a minimum, we can go to Group 9, having the highest red hardness. Perhaps any one of the classes in Group 9 would do this job but under such circumstances preference is often given to a compromise type as a factor of safety against insufficient toughness and future broken tools.

Example 7 — Required to make a ⅞-in. diameter staybolt tap, 20 in. long. By referring to our target working diagram, page 668, we see that Groups 2, 6, and 10 are used for the majority of cutting applications. *(Continued on page 690)*

By The Editor

Critical Points

TO COLUMBUS, to the annual all-day meeting of the Cincinnati, Dayton and Columbus Chapters, where several experts discussed the general topic of quenching. As is true of many other fine technical meetings, most of the subject matter was already on the record, but what with the many diversions of 1940 living, a lot of it was new to the large audience or at least, if known, partly forgotten. . . . . HOWARD SCOTT of the Westinghouse Research organization talked about the three classes of quenching media (water, oil, air-gas), the three classes of steels adapted therefor, and the three outstanding effects on the steel (hardening, distortion, cracking).

How to Avoid Distorted and Cracked Dies

I. Water hardening of water hardening steels gives a thin martensitic shell that is in compression and therefore relatively free from cracking, although warpage is the big problem. SCOTT emphasized that salt solutions have largest cooling power at certain concentrations — 9% for common salt and 3% for caustic soda. II. To minimize distortion the steel may be oil quenched, but to come out hard it must contain considerable alloy. Deep hardening leaves tension stresses at the surface and oil quenching steels are most susceptible to cracking. Likewise scale on the hot steel does not clear itself readily in oil, as it does in water or brine, and may cause soft spots. III. To prevent both distortion and cracking, a more expensive high alloy, air hardening steel may be used. These require long, high temperature treatments, so adequate protective atmospheres are essential during heating and cooling. New steels of air hardenability that are in the price and quenching range of the oil hardening steels are now on the market, and GORDON WILLIAMS writes that at least one of them in the uses he has tried is as good as claimed (which is amazing).

COMMERCIAL applications of the austempering process were described by ELMER LEGGE of American Steel and Wire Co. As is well known, the process consists of quenching steel into molten baths (at something less than 900° F.) and holding there until the transformation into bainite is complete. At hardness levels between C-44 and C-58 this microstructure is superior to tempered martensite, being much more ductile. As an instance of its application take hollow rollers for bicycle chain. They are tested by compressing them flat. Quenched rollers of S.A.E. 3150 must be drawn back to C-41 to stand this test (which represents freedom from breakage in service). Austempered rollers of S.A.E. 1065 will do it at C-51; the extra hardness means doubled abrasion resistance.

Parts Sizes Limited for Austempering

LEGGE said that while plain carbon steel had a practical size limit of 1/8 in. diameter for austempering in 2 to 3 hr., the size could be doubled by boosting the manganese a little, increased to 1/2 in. by further adding 0.25% molybdenum, and even going to 2 in. or more by higher alloy like S.A.E. 4365. The Worcester plant of his company has a 500-lb. per hr. furnace doing custom work on pre-formed stampings and simple shapes such as chipping chisels, safety toe caps, knife blades and lock washers.

JOHN BURNS told of some tricky quenchings that might be used on emergency to avoid cracks in the hardened pieces. First is the "time quench" — removing the article after a definite time in the water. When this is properly done the surface hardness is less than the maximum possible, although the hardnesses at depth are

little changed. Second is "double quenching" — changing to an oil bath after definite time in water. Third is the "interrupted quench" (in water a few seconds, out into air and then back into water). The last two operations will produce soft surfaces of troostite over a zone of harder martensite. These operations are suggestive of the traditional hardening of springs wherein the leaf is removed from the quench hot enough to "flash off" oil, and retaining enough heat for self tempering. Such spring tempering is out of favor because it cannot produce uniform results; so BURNS emphasized that such quenching programs in production would require careful and automatic control. However, this might be economic if the part could be made thereby of a less expensive (lower alloy) steel. The one use he knew of was for track links for tractor treads, where only one surface needs to be hard. . . . . SAM HOYT, technical chairman of the meeting, said it was worthy of mention that Dr. BURNS was not only a Doctor of Science but an operating executive, being superintendent of the wire division of Republic Steel Corp. at Chicago. He might have added that the talk was as noteworthy as the talker; whereas Messrs. MCQUAID and EHN, 25 years ago, earned fame in showing how to avoid soft spots in quenched cylinders, BURNS now comes and shows how to spread the soft spot over the entire surface!

Tricky Quenches

INDUCTION hardening as promoted by Ohio Crankshaft Co. has been so well publicized that the methods used by Budd Induction Heating and described by LLOYD JACKSON of Battelle Memorial Institute for hardening the bore of automobile front axle hubs may be dismissed by saying that a 4-in. coil carrying several hundred kilowatts of high frequency oscillating power is automatically lowered into the bore, after which a high pressure water spray gives an immediate and drastic quench. These hubs of S.A.E. 1045 come out C-62 hard, and hardness extends about 0.06 in. deep; the entire cycle occupies about 2 sec. The two bearing races are so hardened, and the operation is very economical since the races formerly had to be hardened as rings and then fixed in place at accurate centering and angularity. Other items coming into similar production hardening are cylinder liners, pump sleeves, and diesel sleeves, the latter of gray iron. . . . . The speed at which these actions take place is infinitesimal in relation to the times at temperature recommended for furnacing operations, yet evidently not too little for the essential action, namely, carbon diffusion into the iron. EDGAR BAIN in his "The Alloying Elements in Steel" shows micros of spheroidized low carbon steel quenched after 5 sec. at heat, and enough carbon has penetrated in that short time to give martensite shells 0.0001 in. thick about the undissolved carbides. This is ten times the half-thickness of the ferrite lamellae in coarse pearlite, so even a 2-sec. cycle would be long enough for full hardening at, say, 1500° F. Also it is possible that temperatures (and diffusion rates) in the zone of atoms being kicked around by rapidly alternating currents are higher than supposed.

Blitzkrieg Induction Hardening (Internal)

AT BUCKEYE Steel Castings Co., Columbus, found a mammoth plant expressly for casting frames, bolsters, couplers and other parts of railroad trucks and draft rigging. The metallurgical engineer, SAMUEL KRUMM, had followed the Editor's pre-War trail through college to the Montana copper industry, so there was plenty of reminiscing between comments on steel foundry practice. . . . . Resolved to recommend to some other steel makers they find out how W. H. (BILL) HEIMBERGER gets the high flame temperature necessary for a heat of carbon steel out of his 30-ton openhearths every 5 to 5½ hr. (It's good stuff, too, monthly averages being 78,000 psi. ultimate, 27% elongation, and 33 ft-lb. Izod impact on normalized test bars.) His furnaces burn producer gas; unusual attention is given the shape and condition of the ports. The entire end block rests on a big steel casting, is bound together in one piece by a structural shell, and is replaced bodily in 10 min. by overhead crane after seven or eight heats. Connection at the bottom (to gas and air uptakes) is by a water seal, and the joint at the side and roof (to the furnace hearth) is closed by a single course of brick. . . . . Buckeye is vigorously promoting a high strength steel which ought to reduce the dead weight of railroad castings almost 25%. It contains about double the normal manganese (that is, 1.5%) and a ladle addition of 5 lb. ferro-carbon-titanium per ton insures fine grain and uniform distribution of the manganese — that is, 53 ft-lb. Izod toughness and uniform heat treatability.

Good Steel Improved by Mn and Ti

REVISITING Battelle Memorial Institute after several years was impressed with the recent growth in buildings, equipment and staff, there being now about 200 people engaged, three quarters of them researchers and technical assistants. In the ten years of its history the Institute has studied about 430 projects sponsored and largely financed by industry and about 100 additional investigations on their own. As an example of the first, FRED DAHLE demonstrated the comparative cutting ease at heavy cuts of S.A.E. 1045 with and without 0.25% lead, both bars heat treated to the same mechanical properties. The leaded steel produced a short tightly curled chip so cool it hardly colored, while from the unleaded steel came a long open helix at blue heat, and correspondingly hard on the tool. . . . . Successful electrolytic polishing was demonstrated by HOWARD RUSSELL. Several years' work was necessary to discover conditions wherein the various steels, brasses, and other metals could be polished by conditions and controls little more critical than those existing in an ordinary plating tank. In demonstration, a hub cap, stamped from a frosty sheet of stainless steel, was given a brilliantly reflective surface in six minutes. . . . . CLARENCE SIMS showed the development of a new method of adding chromium to a steel bath. The idea, originally MARVIN UDY's, is that a combination of calcium, chromium and iron oxides could be made with silicon metal in such proportions that the substance would start a silico-thermic reaction when thrown into the furnace, the heat generated by the oxidation of the silicon being enough to melt the resulting chromium and iron and the slag, calcium silicate. In this way the addition does not chill the molten steel. Work on this project, sponsored by Chromium Mining and Smelting Corp. of Canada, required the correct formulation, mixing and roasting of electric furnace products to a very low carbon content, and study of their action in the steel plant. Chromium recovery of 90 to 95% in ladle additions is unusually high and constant in a Canadian steel plant using the high carbon material (known as Chrom-X) as a ladle addition for all S.A.E. chromium steels. Several 50-ton heats of 4 to 6% chromium steels have been made with low carbon Chrom-X as furnace additions, where the reaction is complete in 90 sec. . . . . RUSSELL DAYTON was inclined to question the idea that *lubricated* surfaces of metals would momentarily seize, and believes that the "stick-slip" mechanism described in April METAL PROGRESS could occur only during seizing or galling. When DAYTON prepares optically flat surfaces and lubricates them with non-corrosive oil that contains *no* abrasives, they can run without weighable or observable wear. In other words, wear in well-lubricated and run-in bearings is more likely due to corrosion or to abrasive particles carried by the lubricant than to momentary seizure of metal projections.

Rapid Growth at Battelle Memorial Institute

Chromium Added to Steel Baths From Reacting Compounds

Corrosion, Abrasion & Seizure Wear Out Bearings

CRAWLED OUT on a thin limb in telling the Ohio Section, Society for the Promotion of Engineering Education (S.P.E.E.), that despite much talk about the training of engineers — that is, men who will be leaders and planners in the mechanized world of tomorrow — the clear trend is toward the training of hordes of technicians (intelligent machine tenders, observers, draftsmen, inspectors and minor supervisors). This is more than a play on words; probably nothing much can be done about it, for this is the type of job that is being offered the graduates. Industry no longer trains its own apprentices; in fact, the skilled elder craftsmen are being replaced by intricate machines, and the job is to keep them in order and to watch their product continually. Technical schools cannot be blamed for fitting their boys for the proffered jobs. The educators themselves recognize this trend, for the "engineering" colleges no longer give the degree of "Engineer" for four years' work but "Bachelor of Science in Engineering". Likewise the latest pronouncement of the S.P.E.E.'s committee on desired changes in the curriculum freely uses the term "technological education" to describe the aim. If men must be trained to the profession of engineering, it seems obvious that the engineering schools will have to do what the schools of medicine, law and architecture have done in the training of men for their respective professions — namely, extend the course of study to six or seven years, for even a young engineer cannot get in four years the preliminary training it takes his professional brother six or seven to absorb.

Technicians or Engineers?

Personals

John A. Staples ⊕ is now connected with the Lewin Mathes Corp. of East St. Louis, Ill., as superintendent of the tube mill.

Frank J. Stanley ⊕, formerly superintendent of Crucible Steel Casting Co., Cleveland, now holds the same position at Lebanon (Pa.) Steel Foundry.

Transferred by Jones & Laughlin Steel Corp.: **J. H. Flaherty** ⊕, from the Aliquippa Works to the position of metallurgist of the Pittsburgh Works.

William F. Chubb ⊕ of London has been invited to act as technical adviser to the Air Ministry in Ottawa, Canada.

Robert W. Wilson ⊕, patent attorney, has been elected president of the Cleveland Patent Law Association.

Harry L. Daasch ⊕, formerly associate professor, Department of Mechanical Engineering, Iowa State College, is now professor and head of mechanical engineering at the University of Vermont, Burlington, Vt.

W. S. Newton ⊕, has transferred from repair officer, Submarine Force, Asiatic Fleet, to officer in charge of metallurgical and testing section, Naval Gun Factory in Washington, D.C.

Fred W. Johnson, Jr. ⊕ has left L. F. Grammes & Sons, Inc., Allentown, Pa., to join Kellett Autogyro Corp. in charge of heat treatment.

R. E. Richmond ⊕, formerly a member of the engineering staff at the Portland, Ore., plant of the Electric Steel Foundry Co., now represents the company in sales and engineering capacities in Milwaukee.

E. A. Thomas ⊕ is with Thompson Products, Inc., as sales engineer in the Detroit plant.

James C. Crook ⊕ is now salesman in the Chicago office of Bethlehem Steel Co.

L. M. Clegg, formerly senior vice-president of the Thompson Products Co., Inc., is now executive vice-president in charge of all plant and customer operations.

Phil L. Capy has been appointed district engineer for the Despatch Oven Co. in the State of Texas at Dallas.

George M. McGranahan, now assistant chief engineer at The Dow Chemical Co.'s Midland plant is being transferred to Freeport, Texas, to become director of production engineering.

Charles G. McCabe, formerly with American Rolling Mill Co., has been added to the technical staff of Battelle Memorial Institute, to assist in work on the chemistry of the openhearth steel process.

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Personals

Promoted by Wyman Gordon Co.: **A. J. Pepin** ⊕, from metallurgist at the Ingalls-Shepard Division, to chief metallurgist of the company in Worcester, Mass.

William D. Hibbard ⊕ is now employed by the Duquesne Light Co., Pittsburgh, as an assistant field chemist at the Colfax plant.

Harry W. Highriter, vice-chairman of the New Jersey Chapter ⊕, has resigned from the research staff, Lamp Division, Westinghouse Electric & Mfg. Co., Bloomfield, N. J., to join the research staff of Fansteel Metallurgical Corp., North Chicago, Ill.

G. A. Landis ⊕, formerly in the metallurgical department of Ingersoll Rand Co., Phillipsburg, N. J., is now metallurgist for E. W. Bliss Co., Brooklyn, N.Y.

William B. Hurley ⊕ has not terminated his position with Detroit Edison Co., as stated in May Metal Progress, but remains as staff engineer in the sales department, the appointment as assistant district chief of the Detroit Ordnance District, being in addition to his present duties with Detroit Edison.

Jack L. Wilson ⊕ has left Bethlehem Steel Co., where he was assistant metallographist in charge of alloy and toolsteel laboratory, to become metallurgist for the Peninsular Steel Co., Cleveland.

Awarded an Edward Longstreth medal by the Franklin Institute: **Richard L. Templin** ⊕, chief engineer of tests, Aluminum Co. of America.

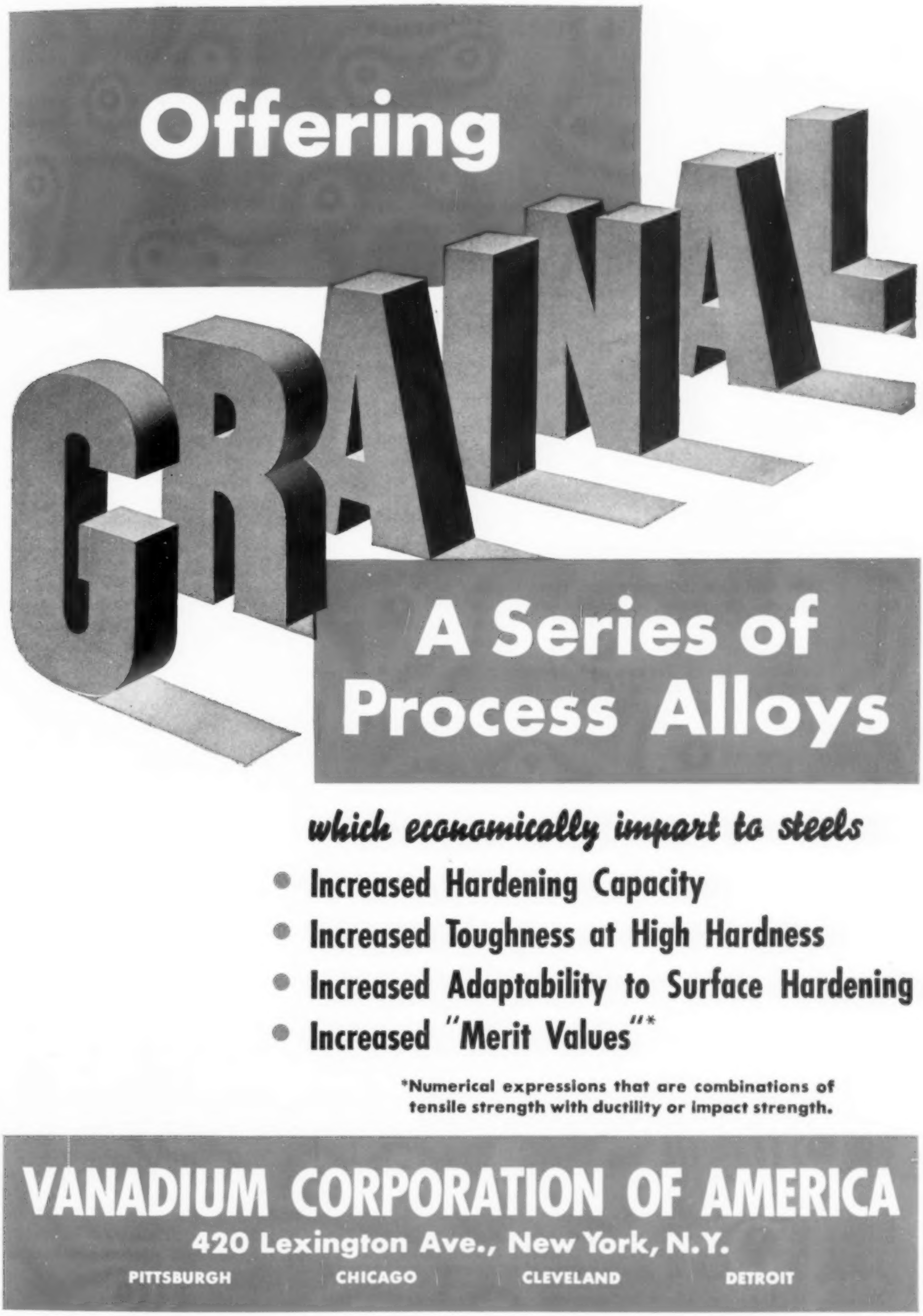
Russell M. Allen ⊕, formerly assistant to the president, Allegheny Ludlum Steel Corp., has been made general manager of sales. **C. B. Boyne** ⊕ has been made manager of stainless sales, his previous position as manager of stainless bar and wire sales now being filled by **J. R. Kumer**, formerly assistant manager. **Louis F. Lippert** is now manager of Pluramelt sales for Allegheny Ludlum.

Charles F. Seck ⊕, formerly special production investigator for Automatic Electric Co., is now designer with Schweitzer and Conrad, Inc., Chicago.

Tom Barlow ⊕, formerly metallurgical engineer in the Copper Iron and Steel Development Association, Cleveland, is now foundry engineer, Vanadium Corp. of America, in Detroit.

Charles T. Evans, Jr. ⊕, B.S. in metallurgical engineering, University of Michigan, Feb. 1940, has been employed as a metallurgist with Universal-Cyclops Steel Corp., Titusville, Pa.

Joseph V. Emmons ⊕, metallurgist, Cleveland Twist Drill Co., has been presented a Modern Pioneers Award by the National Assoc. of Manufacturers.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Endurance of Sucker Rods

By D. R. Dale and D. O. Johnson

[Abstract and summary of a paper entitled "Laboratory and Field Endurance Values of Sucker-Rod Materials" presented to the American Petroleum Institute, May 30, 1940]

Sucker rods, used for pumping oil from deep wells, are subject to failure by corrosion fatigue, as in many regions the oil is accompanied by corrosive gases or brines. The phenomena of corrosion fatigue have been studied extensively, and the mechanism is as follows:

Corrosion forms a pit or notch, sometimes microscopic in character, at the root of which stresses are increased greatly over the normally applied fiber stress. From this concentrated overstress a crack is formed, resulting in a progressive rupture, proceeding transversely, with no plastic deformation of the metal. When the remaining cross-sectional area is too small to sustain the applied load, final failure is of the typical tensile type, with accompanying reduction of area.

Corrosion fatigue tests have been divided roughly into four classifications: Slow speed and high speed tests in the presence and in the absence of oxygen. As far as the production of oil is concerned, B. B. Wescott was the first to recognize that subsurface materials should be tested in the absence of oxygen. His equipment utilizes a rotating specimen of standard size in an R. R. Moore machine, but the specimen is submerged in liquid within an air-tight rubber sleeve. Natural or synthetic brines and oils are recirculated in a closed system, preventing the entrapment of air; temperature and pressure are regulated.

Many such fatigue tests have been made with synthetic brine, and the endurance values used as a guide to determine the safe loads. Ample service records indicate that better performances have resulted, and it is our present purpose to indicate how laboratory tests compare with the service of two steels "A" and "B" in wells in Oklahoma, Kansas and West Texas.

Speed of laboratory testing is of relatively small importance when testing for fatigue in air, but since corrosion is a matter that continues with time, *time* (or the speed of alternation) must be taken into account in sucker rod testing. Laboratory tests fail to duplicate actual service in many other respects. Size of specimen is obviously much different. The surface is not in the smooth condition of the test piece. Dangerous stresses in sucker rods alternate from a high tensile stress to one not so high,

(Continued on page 686)

Endurance

(Continued from page 680)

whereas in the rotating beam test the stresses alternate between equal tension and compressive stresses.

Laboratory tests on Steel B in a synthetic and representative Oklahoma brine show a knee in the S-N curve at about 30,000 psi. stress and an endurance limit at 10,000,000 alternations of about 27,000 psi. However this steel, operating in Oklahoma wells making water, fails very rapidly when stressed at 25,000 to 30,000 psi. In other wells making no water the chances for early fatigue are not so great, but the fatigue data follow the laboratory trend. The records indicate that 20,000 psi. is nearer the true endurance limit of the actual sucker rods in service.

In the Kansas wells is found a combination of fairly heavy loads, corrosive brine, and hydrogen sulphide. Steels A and B, tested in the laboratory at 1750 r.p.m. in Kansas brine, develop characteristic S-N curves and endurance limits at 10,000,000 reversals of about 11,000 and 19,000 psi. respectively. The actual field performance shows points that cluster in a general way along this curve.

In the West Texas wells are comparatively light loads, but extremely bad surface pitting by brine and hydrogen sulphide, so that early failure results at comparatively low loads. Steel A, tested in the laboratory in Texas brine at 1750 r.p.m., did not fail until nearly 5,000,000 reversals at 17,500 psi.; in the field the sucker rods lasted from 600,000 to 2,250,000 reversals under the same stress. Steel B tested in the laboratory at 1750 r.p.m. had a knee in the S-N curve at about 20,000 psi. and 6,500,000 repetitions; when tested at 36 r.p.m. failures occurred in 1/7 to 1/8 the number of reversals. Service records plot in a zone that indicates an S-N curve whose upper end corresponds to laboratory tests at this slow speed; a knee appears at about 17,500 psi. and 1,500,000 repetitions, and an endurance limit at 10,000,000 repetitions of about 12,500 psi.

We hope in presenting this paper to show that we have now reached the place where, on a few steels, we are able to correlate field and laboratory results. Until all endurance value data have been established on a standard basis, endurance values of two steels, for instance, should be compared only when run with identical brines and speeds in standard conditions. Unless this precaution is taken, false — and even dangerous — conclusions may be obtained. As the large amount of published data at this time is based on 1750 r.p.m. with established synthetic brine, this procedure offers the largest field for safe material comparisons until other data, at standard slower speeds and with actual field brines, are available on a sufficient scale.

Rapid Refining

(Continued from page 660)

Marked dephosphorization is obtained by this means in a few minutes. In everyday practice the phosphorus content of the steel is reduced from 0.050% to less than 0.020%.

The actual sequence of operations is as follows:

Thomas steel is blown normally in the converter to a phosphorus content of 0.040 to 0.050%; it is then poured into a ladle and the mixed reagents thrown in. A vigorous stirring action ensues. The reactions come to an end while the ladle travels to the electric furnace. The alkaline slag, which has floated to the surface, is kept back when the steel is poured into the furnace by means of a dam or tea-pot spout.

The work in the electric furnace consists only in covering the bath with a thin layer of neutral slag, and reheating the steel to proper casting temperature. During this time the manganese percentage is adjusted.

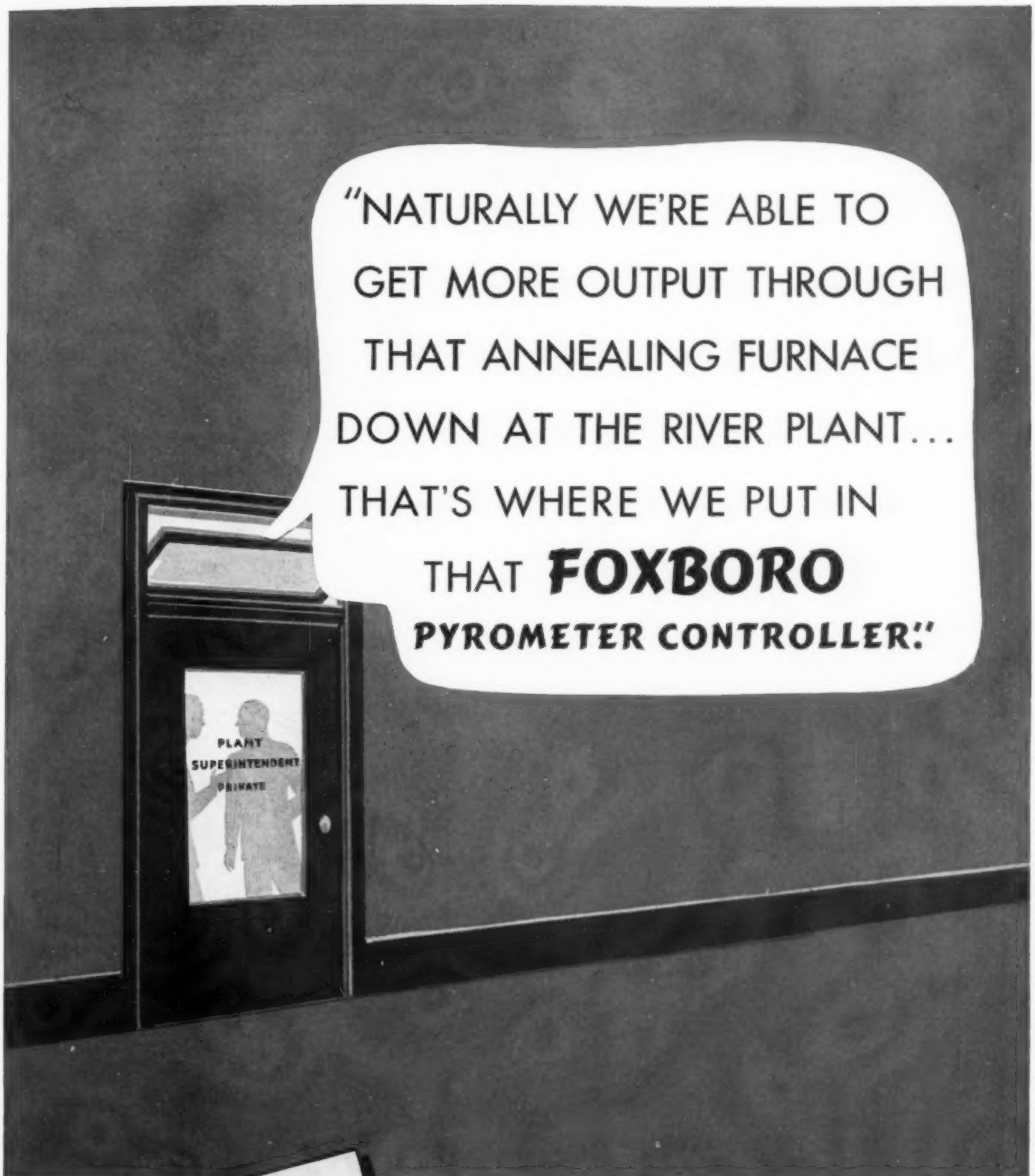
The whole of the operation in the electric furnace lasts between 40 and 50 min. and requires an energy consumption of about 100 kwh. per ton of steel, working with quantities of about 20 tons.

These figures imply a notable saving over the normal duplex method which requires at least 2½ hr. in the electric furnace and energy consumption of at least 250 kwh. per ton of steel. Compared to these economies, the price of the reagents is slight.

Another advantage is the very notable improvement in the steel. The gaseous stirring which occurs in the ladle has the effect of bringing the gases dissolved in the steel toward equilibrium, and finally induces a very regular rimming action in the ingot molds. Cropping of the ingot for rolling can therefore be considerably reduced, and a first quality product is obtained.

Taking as a basis of comparison the mechanical properties mentioned at the beginning of this note, we find that this new treatment can normally give elongations of 34 to 36% with tensile strengths of about 50,000 psi. This is even an improvement in comparison to the rimmed soft steel normally produced in the openhearth.

ALBERT M. PORTEVIN
Bessemer Medalist
Consulting Engineer



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Toolsteels

(Cont. from page 670) Since the dimensions of the tap offer quite a problem for a water hardening steel and the abuse it will get makes it uneconomical to use high speed steel (unless sectional taps are employed) a Group 6 steel should be selected.

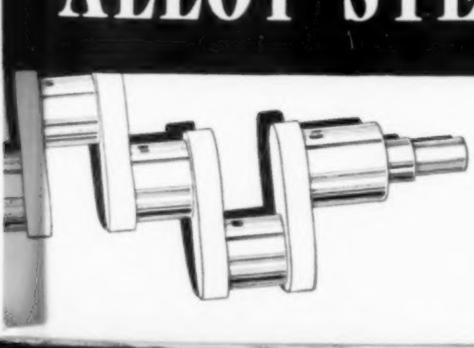
Example 8 — Required to make a hot header die for rivets, with the use of water cooling. Referring again to our working diagram we see that Groups 3, 7, and 11 are used for most die work. Since this is a hot work application we pass immediately to Group 11, and as header dies necessarily require good resistance to shock it is best to select one of the tougher types. However, the footnotes to the data sheet indicate that the use of water with tungsten steels is more or less dangerous, and in many instances it will be found economical to pass to one of the Group 12 steels because they withstand the use of water to a much greater extent.

Example 9 — Required to make a 4½-in. wide by 2-in. thick by 8-in. long roll-threading die for large bolts. By referring to our target working diagram on page 668, we see that Groups 3, 7, and 11 are used for most die work. As this is a cold work application which must be hardened without distortion because of the threads, a Group 7 steel may be selected. However, since such applications are not subject to any appreciable shock it would be more economical for applications where potential production is large and of a standard nature to go to a Group 5 steel having maximum resistance to wear. The air hardening types are usually preferred for such heavy dies because they offer less of a problem in quenching.

Example 10 — Required to make pneumatic rivet sets. By referring to our working diagram on page 668, we see that Groups 4, 8, and 12 are used when maximum toughness must be obtained, as is obviously required by rivet sets. Since this application does not represent a hardening hazard and does not require sufficient resistance to heat to make it necessary to use a Group 12 steel, we can select a Group 4 water hardening steel without hesitation. A steel with the least hardenability is usually preferred because it produces a tougher core together with sufficient surface hardness.

In conclusion, it is hoped that by printing this article some measure of a contribution has been added to the efforts being made to clear up industry's notion about toolsteels as a whole, and at the same time help minimize the uncertainty that consumers often manifest when confronted with the problem of selecting a toolsteel for a given duty.

ALLOY STEELS



Large Gears

(From page 657) A. L. Boegehold has found *(Transactions* ⊕, 1937, p. 245) that the endurance limit of hardened carburized steel at 250° F. is at least 10% lower than at room temperature. These results might have been affected by the lubricating oil used to maintain the temperature.

Research and experience have indicated that the mechanism of pitting of gear teeth is decidedly affected by the lubricant. It is not known whether the action is related to the initial development of the pits or whether it merely acts to accelerate failure. It has been adequately demonstrated that liquids, especially of a corrosive nature, reduce the fatigue life of standard specimens.

Impact: All gear materials are subjected to impact loads because mating gears constitute a loosely coupled elastic system. No satisfactory methods of evaluating impact properties by test or otherwise have been developed. The Charpy or Izod tests are a useful criterion of heat treatment and quality, but the correlation and interpretation must be based upon experience. These tests are a measure of notch sensitivity or resistance to deformation.

Conclusion

A continuation of the theoretical research into the metallurgical factors affecting gear service will result in substantial returns. Such theoretical exploration, in conjunction with improved steels and an increased knowledge of heat treating processes, enables the gear metallurgist and designer to cooperate and secure optimum gear performance. Available are a choice of quality steels of different carbon and alloy contents especially suitable for gears to be carburized, hardened after cutting or heat treated before machining. A more thorough knowledge and appreciation of casting and forging technique have resulted in a wider scope of application for gear purposes.

The status of gear metallurgy is constantly changing. The conditions of lubrication, mounting, manufacturing and accuracy are continually improving, thereby requiring the manufacturer to be ever on the alert for factors which demand modifications in selection or judgment. Many of the good practices of today will tomorrow be the mistakes of yesterday. ⊕

Notes About Contributors

TWO DEGREES in chemical engineering prepared **Clarence L. Altenburg** for two years as mechanical engineer for Detroit Street Railways. Chemistry came to the fore again, however, when he became technical director of the then General Reduction Corp. for some seven years, during which time he was also in charge of the chemical engineering department of University of Detroit. Since 1934 he has been with Great Lakes Steel Corp. as research engineer. Mr. Altenburger takes his sports early, having spent the latter half of May vacationing in the wilds of Canada.

Harold B. Chambers is proud of the fact that he has been a member of the and associated with steel metallurgy since his graduation from Lehigh University in 1925 with the degree of metallurgical engineer. Following graduation, he spent a little more than a year with the Pittsburgh Crucible Steel Co., Midland, Pa., and then became associated with the Steel Division of the Timken Roller Bearing Co., Canton, Ohio. In 1931 he moved to Canada and joined Atlas Steels Limited in Welland as metallurgist. Transferring to the Ontario Chapter, he was elected its chairman in the 1936-37 season.

Getting his B.S. at Penn State in 1929, **Max. W. Lightner** went to Carnegie Tech for his master's degree, and stayed on as research engineer at the Metallurgical Advisory Board to Carnegie Tech until 1933. Since then he has been at Homestead Steel Works of Carnegie-Illinois Steel Corp., serving in various capacities in the metallurgical and openhearth departments until 1937, when he was made chief metallurgist. [Flash! Lightner has just been promoted to assistant to the general superintendent of Homestead.] His report of the openhearth conference on page 647 is not his first introduction to readers, since he is also author of the first two chapters in the book on "Modern Steels" recently published by the Society. Mr. Lightner's official connections are not given under his "by-line" on page 647, for the report was made by him as an unofficial observer, and the U.S. Steel Corp. does not necessarily agree with any of the statements made therein.

One of the most faithful contributors to METAL PROGRESS's foreign correspondence columns is **Albert M. Portevin,** who has been sending regular letters from Paris for the past decade. A graduate of Ecole Centrale des Arts et Manufactures (circa 1900), he is now a professor there as well as at Ecole Supérieure de Fonderie (foundry) and at Ecole Supérieure de Soudure Autogène (welding). He likewise serves as consulting engineer for various metallurgical companies and is general secretary and vice-president of the editorial committee for *La Revue de Metallurgie*, the leading French metallurgical magazine. Professor Portevin is the author of over 250 papers and the breadth of his experience is reflected in the wide range of subjects he has treated in the pages of METAL PROGRESS. He is a chevalier of the Legion of Honor, honorary president of the Association Technique Fonderie de France, Bessemer medalist and Carnegie gold medalist of the British Iron and Steel Institute. Among his other honors is an honorary membership in the American Institute of Mining and Metallurgical Engineers.

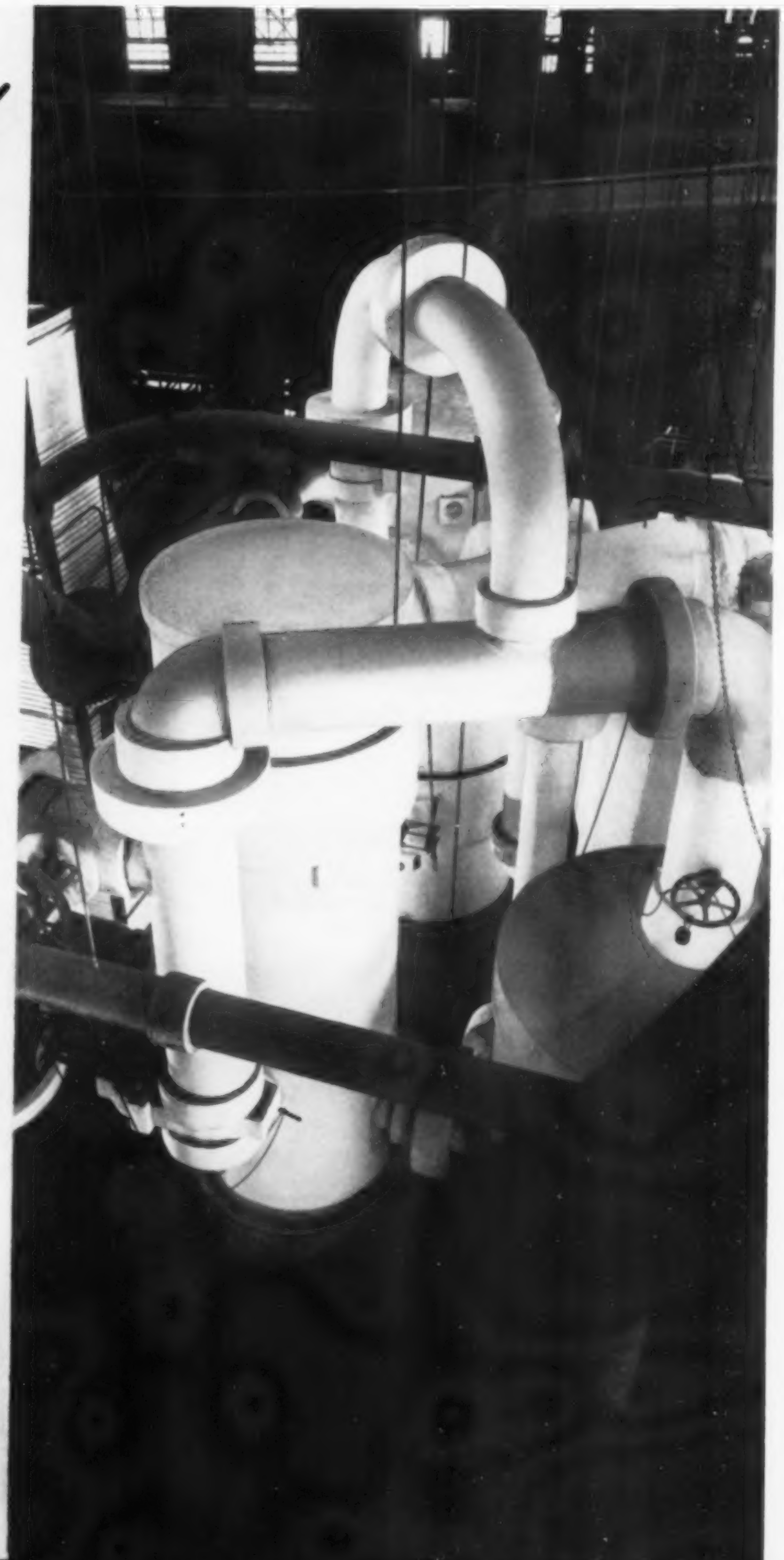
Edward J. Wellauer has been in charge of metallurgical work for the Falk Corp., Milwaukee, for several years and was recently appointed research engineer. A more extended biography has been printed in the December 1939 issue, which carried the first installment of his article on metallurgy of large gears.

Harold B. Chambers

Clarence L. Altenburger

Edward J. Wellauer

Albert M. Portevin



Uranium

(Continued from page 646) the German occupation of Holland, the author's ancestral home, would doubtless be phrased today in more positive terms.]

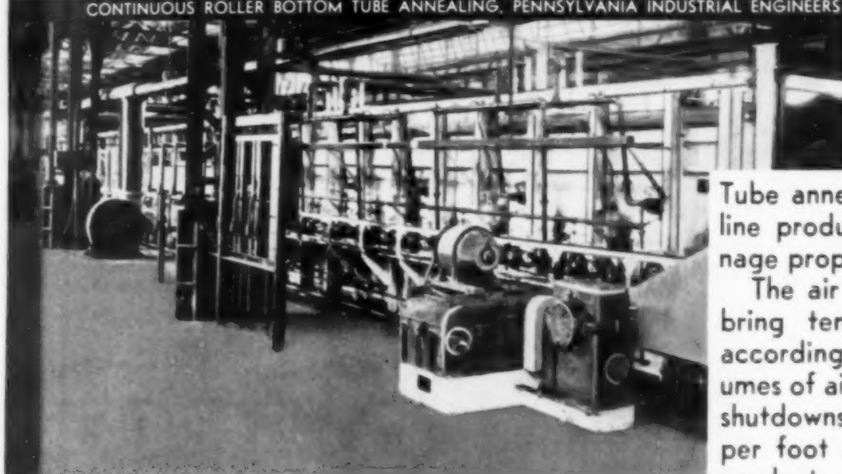
It's now "nuclear fission", real atom smashing. Dr. DARROW summarizes the situation in the *Bell System Technical Journal* for April. If a slow moving neutron (a unit of mass, either with no electrical charge, or of balanced positive and negative charges) gets inside the defenses of an uranium atom, it splits the uranium wide open into two new atoms, one weighing about 60% of the original and the other about 40%. Likewise there seems to be no constancy in the matter, so a neutron bombardment of considerable uranium will produce the whole series of chemical elements between selenium and barium with innumerable isotopes thereof. Sufficiently unorthodox! But it is worse than that. The fission products do not add up as far as mass is concerned — there is a superfluity of "rest-mass" (as relativity puts it) which manifests itself in a high kinetic energy of the two fragments. Likewise there is a wholly unprecedented shower of particles cast off — the disturbing part being that there are more neutrons formed than it takes to start the reactions. More neutrons emerge than are spent. So what? Let Dr. DARROW answer the question:

"Must we not anticipate a self-sustaining, nay even a self-amplifying effect? Must we not fear, in fact, a cataclysmic explosion? Were anything of the sort to happen, we may take it for granted that the world would know of it, though in all probability the experimenter would not himself survive to report it. Evidently then it has not happened, and there must be a brake or brakes in Nature which impede the slide toward the catastrophe, and have thus far averted it. In other words, there must be ways in which the evolved neutrons are made harmless by some innocuous type of capture, before they ever produce a fission." Seemingly the danger would be acute if a certain isotope of uranium were to be accumulated in considerable quantity and visited by an aimless neutron. Dr. DARROW ends with the rather slender hope "that those who build up great masses of sensitive uranium will recognize preliminary signs that the danger-point is close, before they actually attain it."

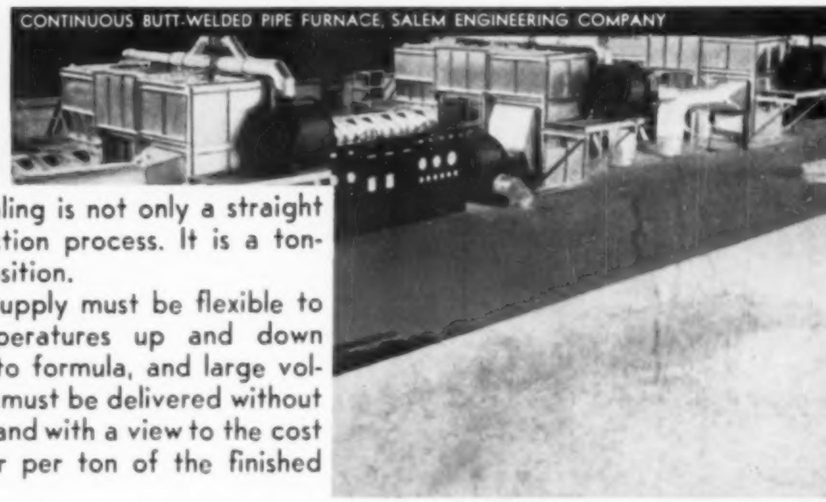
TUBE ANNEALING

CONTINUOUS ROLLER BOTTOM TUBE ANNEALING, PENNSYLVANIA INDUSTRIAL ENGINEERS

CONTINUOUS ROLLER BOTTOM TUBE ANNEALING, PENNSYLVANIA INDUSTRIAL ENGINEERS



CONTINUOUS BUTT-WELDED PIPE FURNACE, SALEM ENGINEERING COMPANY

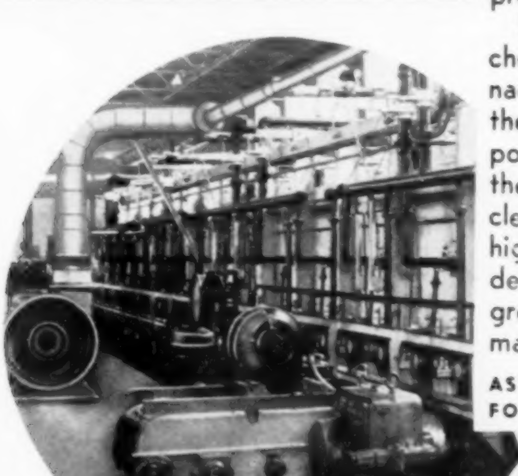


Tube annealing is not only a straight line production process. It is a tonnage proposition.

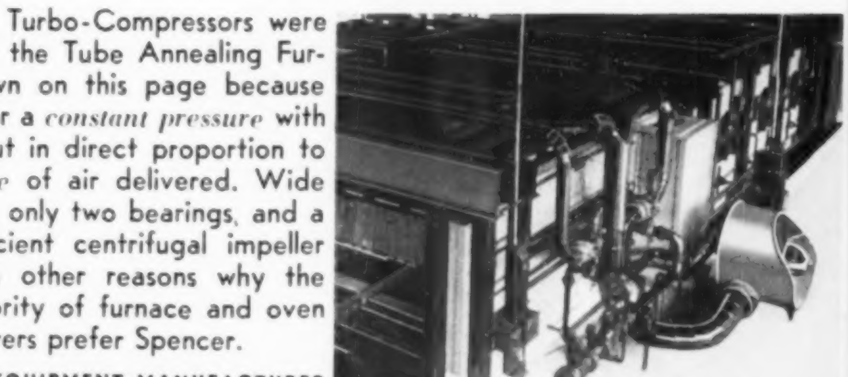
The air supply must be flexible to bring temperatures up and down according to formula, and large volumes of air must be delivered without shutdowns and with a view to the cost per foot or per ton of the finished product.

Spencer Turbo-Compressors were chosen for the Tube Annealing Furnaces shown on this page because they deliver a *constant pressure* with power input in direct proportion to the *volume* of air delivered. Wide clearances, only two bearings, and a highly efficient centrifugal impeller design are other reasons why the great majority of furnace and oven manufacturers prefer Spencer.

ASK YOUR EQUIPMENT MANUFACTURER FOR THE SPENCER TURBO BULLETINS



CONTINUOUS ROLLER BOTTOM TUBE ANNEALING, PENNSYLVANIA INDUSTRIAL ENGINEERS



CONTINUOUS CENTRIFUGAL PIPE ANNEALING FURNACE, R-S PRODUCTS CORPORATION

184-F

SPENCER HARTFORD TURBO COMPRESSORS

35 TO 20,000 CU. FT. 1/3 TO 300 H.P. 8 OZ. TO 5 LBS

THE SPENCER TURBINE COMPANY • HARTFORD, CONNECTICUT

HELPFUL LITERATURE

Some of the foremost experts in the metal industry have contributed to the wealth of information contained in the literature described on this page. You will find your time well spent in looking it over. One booklet may solve your most difficult problem. Use the convenient coupon today to obtain this free literature.

No Decarburization

A low cost method of hardening and annealing under production conditions with no decarburization is described in technical data available through Westinghouse Electric & Mfg. Co. Bulletin Fd-134.

Pyrometers, Furnaces

Two new broadsides issued by Leeds & Northrup will be of value to those interested in indicating, recording, or controlling industrial temperature, as well as heat treating furnaces. Bulletin Fd-46.

Nickel Alloy Steels

Typical nickel alloy steels and cast irons employed in Diesel engine construction are charted in a folder by the International Nickel Co. Bulletin Fd-145.

Eutectrol Carburizing

Actual operating data and pictures of the Surface Combustion Eutectrol furnaces are included in a colorful folder just released. Bulletin Fd-51.

Stainless Steels

A wealth of information on Republic ENDURO Stainless Steels is contained in a new booklet issued by Republic Steel Co. Bulletin Fd-8.

Brazing Silver Alloys

A new and colorful folder just released by Handy & Harman is full of interesting pictures showing how metals can be joined with better, more economical results with SIL-FOS and EASY-FLO. Bulletin Fd-126.

Stainless Electrodes

Helpful material on the selection of correct electrodes for electric arc welding of Stainless Steels is contained in a new folder by the Crucible Steel Company of America. Bulletin Fd-56.

Tool Steel Selector

A new chart of Tool Steel Recommendations which helps you select the Best Steel for each tool is available through the Jessop Steel Co. Bulletin Fd-173.

Instruments

A very colorful brochure which describes "Bristol's 50th Anniversary Instruments" illustrated many interesting developments. Available through the Bristol Co. Bulletin Fd-87.

Electric Furnaces

A new 24-page catalog has just been released by the Detroit Rocking Electric Furnace Co. Bulletin Fd-271.

Steel Stock List

A handy pocket-size booklet containing an explanation of the change in steel classifications and extras, as well as general data tables, is now available through Joseph T. Ryerson & Sons, Inc. Bulletin Nb-106.

Alloy Steels

Why alloy steels are best for heavy equipment and other exacting applications is discussed in a folder by Bliss & Laughlin, Inc. A partial list of the more common grades gives machine ratings and turning speeds. Bulletin Jy-42.

Off the Payroll

"Deadweight is off the payroll with U.S.S. High Tensile Steels" is the title of a new folder issued by U.S. Steel. Contains not only technical information which is of particular interest to engineers but additional information of general interest. Bulletin Ib-79.

Cr-Ni-Mo Steels

A. Finkl & Sons' catalog is really a technical treatise on chromium-nickel-molybdenum steels for forgings. Pocket size, 104 pages, cloth bound, illustrated by photographs, charts and tables. Bulletin La-23.

Welding Ideas

Illustrating and describing a wide variety of money-saving repair, fabrication and structural applications of arc welding, a new bulletin "101 Welding Ideas for Low Cost Maintenance" is available through the Lincoln Electric Co. Bulletin Kc-10.

Globar Elements

Globar Pin Type Non-Metallic Electric Heating Elements and Terminal Rods and Globar "AT" Type Non-Metallic Electric Heating Elements are explained and illustrated in two booklets issued by the Globar Division of the Carborundum Company. Bulletin Lb-25.

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Tool Steel Guide

A 36-page booklet which gives a clear picture of the entire range of tool steels and their fields of use, plus a systematic method for selecting the right steel for the purpose, is being released by Bethlehem Steel Co. Bulletin Bc-76.

Dust Collecting

Fourteen outstanding features found in Pangborn dust collectors, along with pictures of typical installations and savings, are found in the new Pangborn Bulletin. Bulletin Ad-68.

Chemicals

A complete line of Fluxes, Inhibitors, Zinc, Alkali Cleaners and Acids is described in a new catalog issued by Grasselli Chemicals Dept. of E. I. DuPont de Nemours & Co. Bulletin Dd-95.

Lectromelt Furnaces

The story behind lectromelt furnaces is well told in this 48-page booklet issued by the Pittsburgh Lectromelt Furnace Corporation. Tells of development of this type furnace and describes recent improvements. Bulletin Db-18.

Pyrasteel

All types of uses for Pyrasteel, the heat resisting alloy made by Chicago Steel Foundry Co., from astronomical plaques ruled 20,000 lines to the inch to huge kilns, are described in an illustrated pamphlet. Bulletin Cb-184.

Pot Furnaces

The new features of American Gas Furnace Co.'s improved pot hardening furnaces include insulating refractory lining backed by block insulation, heat resisting alloy burners, single valve control, numerous small burners with their attendant advantages, burner location and method of venting. Fully described in Bulletin Sy-11.

Alloy Castings

The "extra point" value of Michiana alloy castings is shown in a booklet released by the Michiana Products Corp. Typical installations are shown. Bulletin Nb-81.

Magnet Steels

A very handsome booklet describes the permanent magnet steels and castings made by Simonds Saw & Steel Co., including Alnico and Alnic. Bulletin Ba-158.

HELPFUL LITERATURE

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Welding Stainless

How to weld stainless steels is described in a colorful 12-page folder released by the Page Steel and Wire Division of American Chain & Cable Co., Inc. Bulletin Cc-86.

Carburizing Salt

A technical service bulletin describing a new development — Du Pont Carburizing Salt — for the economical production of deep high-carbon cases on plain carbon and alloy carburizing steels . . . available through Du Pont. Bulletin Dc-29.

Structural Metal

A complete and concise discussion of magnesium and its alloys is contained in the booklet "Industry's Lightest Structural Metal" which is made available through the Dow Chemical Co. Bulletin Bd-215.

Design

Designing greater sales appeal into products is explained in a colorful 8-page booklet for anyone who contemplates using, or is using, Stainless Steel, issued by the Carpenter Steel Co. Bulletin Nc-12.

Extrusions and Pressings

The book "Impact Extrusions and Pressings" showing many impact extrusions made of Alcoa Aluminum Alloys, for designers and production men, is available through the Aluminum Company of America. Bulletin Hc-54.

Furnace Experience

Facts developed through 32 years of engineering and building practically every type of industrial fuel equipment can be obtained through Flinn & Dreffein Co. Bulletin Bc-82.

Mo-W High Speed

J. V. Emmons, metallurgist for Cleveland Twist Drill Co. and largely responsible for the development of the molybdenum-tungsten high speed steels known as Mo-Max, has prepared a general description of these new steels. Bulletin Ka-103.

Ingot Production

"The Ingot Phase of Steel Production" is the title of a book defining the principles of quality ingot production followed by many well-known steel manufacturers. Gathmann Engineering Co. Bulletin Ka-13.

Colmonoy

The high resistance to wear and corrosion which distinguishes Colmonoy alloys and overlay metals is explained in a 4-page catalog released by Wall-Colmonoy Corp. Bulletin Bc-85.

Electric Furnaces

A four page bulletin on ⅛ lb. to 4 lb. high frequency melting furnaces and 3 kw. converter is now available through the Ajax Electrothermic Corp. Bulletin Dd-41.

Aerocase

A modern method for case hardening and heat treating steel in a liquid bath is provided by the use of Aerocase compounds. Their principal features are described by American Cyanamid and Chemical Corp. in an interesting booklet. Bulletin Oy-148.

Seamless Tubes

Prepared by the Timken Steel and Tube Division of Timken Roller Bearing Co. is a "Guide for Users of High Temperature Steels" which presents technical data relating to the various properties of Timken seamless tubes. Bulletin Bb-71.

Heat Resisting Alloys

Authoritative information on alloy castings, especially the chromium-nickel and straight chromium alloys manufactured by General Alloys Co. to resist corrosion and high temperatures, is contained in Bulletin D-17.

Heroult Furnace

Revised and expanded to include modern major innovations in the construction and operation of the Heroult electric furnace, the latest edition of the American Bridge Co.'s Heroult Electric Furnace Bulletin is available. Bulletin Bb-124.

Metal Heating

Improvements in furnace economies, operating conditions and appearance, furnaces that will more satisfactorily meet old requirements or handle new processes, service that will help solve the most stubborn problems are offered and described by Mahr Mfg. Co. in Bulletin Ea-5.

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High-Strength Steel Data

Complete mechanical property data on Ductiloy, a new low-alloy, high-strength steel, are given for strip, plate and bars in a folder of Great Lakes Steel Corp. Bulletin Ec-229.

Mounted Wheel Chart

A convenient ready reference wall chart showing mounted grinding wheels should be of great advantage in the cleaning room, pattern shop, tool and die room, and many other places. It gives at a glance, by means of detailed drawings, actual size, the exact radius of each wheel and its exact shape. Chicago Wheel & Mfg. Co. Bulletin Bd-230.

Heat Treating Hints

A helpful, colorful booklet edited by experienced heat treaters is available through the Lindberg Engineering Co. Bulletin Bd-66.

Free Machining Steels

Speed Case and Speed Treat, two steels with increased machining properties, are described in literature available through Monarch Steel Co. Bulletin Cd-255.

High Speed Steel

Required hardness and extraordinary toughness combine to make Firth-Sterling Co. new high speed steel "Mo-Chip" of unusual interest to manufacturers who need a steel that is "practically indestructible." Bulletin Ad-177.

Oil Burners

North American Mfg. Co. offers a bulletin describing improved low pressure oil burners, one type especially designed for automatic control and ideally suited for use with proportioning control valves. Bulletin Na-138.

Tocco Junior

A new induction hardening machine for hardening small parts is described in a new bulletin released by the Ohio Crankshaft Co. Bulletin Dd-145.

Metallographic Equipment

The 100-page "Metal Analyst" issued by Adolph I. Buehler features new Metallographic Sample Preparation Equipment; a comparative listing of Metal Microscopes, Measuring Microscopes, and Spectrographs; an index of over 1,000 new technical books and papers; and a treatise on the Application of Reflected Light. Bulletin Ed-135.

HELPFUL LITERATURE

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Lubrication

Intensive research which completed important improvements in the field of heavy-duty gear and bearing lubrication is tabulated in a new 12-page illustrated bulletin just released by D. A. Stuart Oil Co., Ltd. Bulletin Lb-118.

Oil Burners

A new model proportioning oil burner giving accurate combustion and temperature control with greater fuel economy is described in a booklet by the Hauck Manufacturing Co. Bulletin Ed-181.

Portable Electric Furnace

A unique portable electric furnace designed for use at temperatures below 1100° F. with drawing salts and oil tempering baths is described in a booklet by Claud S. Gordon Co. Bulletin Ed-53.

Process Control

"Stabilflo Valves", an illustrated folder just issued by The Foxboro Co., describes this rugged, yet extremely accurate, valve for use in process control. Bulletin Ed-21.

Precision Saws

The complete selection of DOALL precision saws supplied by Continental Machines, Inc., is shown in an attractive folder supplied by this company. Bulletin Ed-170.

Strain Gages

A description of strain gages and extensometers handled by Baldwin-Southwark is included in an attractive bulletin just issued. Bulletin Ed-67.

Brazing Furnace

If you have a brazing problem you will be interested in the worthwhile folder issued by Hoskins Mfg. Co. Bulletin Ec-24.

Cutting Oils

An interesting new booklet "Metal Cutting Lubrication — In Theory and Practice" has just been made available by Cities Service Oil Co. Bulletin Ec-113.

Closer Temperatures

Closer temperature control than is possible with any Mechanical Controller is explained in a 12-page illustrated pamphlet just released by Wheelco Instruments Co. Bulletin Nc-110.

Bright Annealing

Various types of electric and fuel-fired furnaces built by the Electric Furnace Co. for bright-annealing wire, tubing, strip and other products are described in an 8-page folder. Bulletin Lb-30.

Ferrocarbo

A cupola addition, "Ferrocarbo", which improves casting quality, lowers costs and reduces rejects is described in literature available through the Carborundum Co. Bulletin Bd-57.

Pure Metals

Pure, carbide-free metals are described and applications suggested in a pamphlet published by Metal & Thermit Corp., who make pure tungsten, chromium and manganese in addition to the ferro-alloys. Bulletin Ma-64.

Moly in Steel

Metallurgists, engineers and production executives who are really interested in the metallurgy of steels and their application will want the excellent book on molybdenum steels published by Climax Molybdenum Company. Bound in loose-leaf manner, this reference book is chock-full of tables which form a volume almost an inch thick. Bulletin Hb-4.

Annual Index

The Annual Index of the Copper Alloy Bulletin published regularly by the Bridgeport Brass Company is now made available through this company. Bulletin Kc-163.

Foundry Sand

A pamphlet recently issued on TAM Foundry Zircon Sand and TAM Zircon Flour contains detailed information on these products of the Titanium Alloy Mfg. Co. Bulletin Hc-90.

Ferro-Alloys

An interesting folder by Electro Metallurgical Co. tells all about their ferro-alloys and their special service to users which will help them to operate their furnaces and make alloy additions under the proper conditions. Bulletin Jy-16.

Machinability Chart

A quick and accurate picture of how Rustless Stainless Steel will respond to your shop operations is given in the "slide-rule" machinability chart available through the Rustless Iron & Steel Corp. Bulletin Bd-169.

Specialized Tester

The Rockwell superficial hardness tester is a specialized instrument for use where the indentation into the work must be kept shallow or of small area, yet sensitivity preserved. A supplement to Wilson Mechanical Instrument Co.'s catalog on the regular Rockwell tester tells all about it. Bulletin Sy-22.

Vacuum Cleaning

A very colorful brochure which illustrates modern cleaning methods by vacuum in industrial plants has been released by The Spencer Turbine Co. Bulletin Dc-70.

Ni-Cr Castings

Compositions, properties, and uses of the high nickel-chromium castings made by The Electro Alloys Co. for heat, corrosion and abrasion resistance are concisely stated in a handy illustrated booklet. Bulletin Fx-32.

Heat Treat Chart

Heat treaters everywhere should find a heat treating wall chart complete with S.A.E. specifications a very valuable addition to their shops. Published by Chicago Flexible Shaft Co., manufacturers of Stewart industrial furnaces. Bulletin Ka-49.

Steel Data Sheets

Wheelock, Lovejoy & Co. gives analyses, physical properties, heat treating instructions, and applications of Hy-Ten, Economo, and S.A.E. alloy steels in concise and easily usable form. Bulletin Ox-74.

Metal Progress, 7301 Euclid Avenue, Cleveland, O.

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